Man and the glacial period

George Frederick Wright, Henry Williamson Haynes

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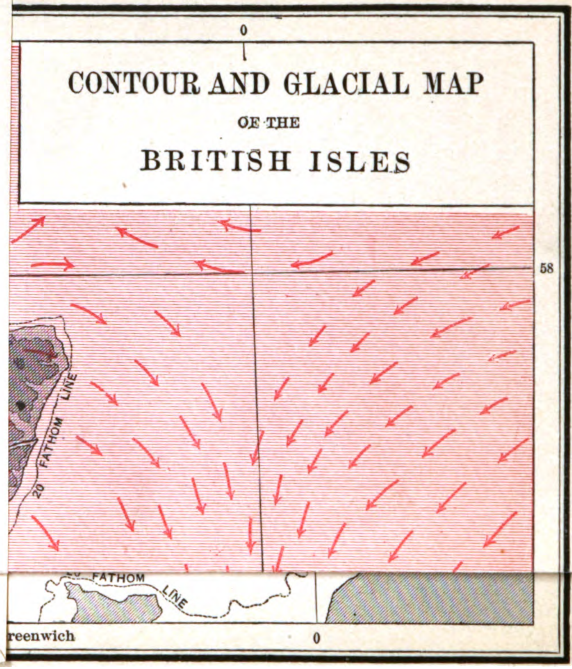
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H. W. Haynes.

THE INTERNATIONAL SCIENTIFIC SERIES

MAN AND THE GLACIAL PERIOD

BY

G. FREDERICK WRIGHT

D.D., LL.D., F.G.S.A.

PROFESSOR IN OBERLIN THEOLOGICAL SEMINARY
ASSISTANT ON THE UNITED STATES GEOLOGICAL SURVEY
AUTHOR OF THE ICE AGE IN NORTH AMERICA
LOGIC OF CHRISTIAN EVIDENCES, ETC.

WITH AN APPENDIX ON TERTIARY MAN

BY PROF. HENRY W. HAYNES

FULLY ILLUSTRATED

NEW YORK
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TO

JUDGE C. C. BALDWIN

PRESIDENT OF THE WESTERN RESERVE HISTORICAL SOCIETY
CLEVELAND

THIS VOLUME IS DEDICATED

IN RECOGNITION OF

HIS SAGACIOUS AND UNFAILING INTEREST IN

THE INVESTIGATIONS WHICH HAVE MADE IT POSSIBLE

PREFACE.

THE wide interest manifested in my treatise upon The Ice Age in North America and its Bearing upon the Antiquity of Man (of which a third edition was issued a year ago), seemed to indicate the desirability of providing for the public a smaller volume discussing the broader question of man's entire relation to the Glacial period in Europe as well as in America. When the demand for such a volume became evident, I set about preparing for the task by spending, first, a season in special study of the lava-beds of the Pacific coast, whose relations to the Glacial period and to man's antiquity are of such great interest; and, secondly, a summer in Europe, to enable me to compare the facts bearing upon the subject on both continents.

Of course, the chapters of the present volume relating to America cover much of the same ground gone over in the previous treatise; but the matter has been entirely rewritten and very much condensed, so as to give due proportions to all parts of the subject. It will interest some to know that most of the new material in this volume was first wrought over in my second course of Lowell Institute Lectures, given in Boston during the month of March last.

I am under great obligations to Mr. Charles Francis Adams for his aid in prosecuting investigations upon the Pacific coast of America; and also to Dr. H. W. Crosskey,

of Birmingham, England, and to Mr. G. W. Lamplugh, of Bridlington, as well as to Mr. C. E. De Rance and Mr. Clement Reid, of the British Geological Survey, besides many others in England who have facilitated my investigations; but pre-eminently to Prof. Percy F. Kendall, of Stockport, who consented to prepare for me the portion of Chapter VI which relates to the glacial phenomena of the British Isles. I have no doubt of the general correctness of the views maintained by him, and little doubt, also, that his clear and forcible presentation of the facts will bring about what is scarcely less than a revolution in the views generally prevalent relating to the subject of which he treats.

For the glacial facts relating to France and Switzerland I am indebted largely to M. Falsan's valuable compendium, La Période Glaciaire.

It goes without saying, also, that I am under the deepest obligation to the works of Prof. James Geikie upon The Great Ice Age and upon Prehistoric Europe, and to the remarkable volume of the late Mr. James Croll upon Climate and Time, as well as to the recent comprehensive geological treatises of Sir Archibald Geikie and Prof. Prestwich. Finally, I would express my gratitude for the great courtesy of Prof. Fraipont, of Liége, in assisting me to an appreciation of the facts relating to the late remarkable discovery of two entire skeletons of Palæolithic man in the grotto of Spy.

Comparative completeness is also given to the volume by the appendix on the question of man's existence during the Tertiary period, prepared by the competent hand of Prof. Henry W. Haynes, of Boston.

I trust this brief treatise will be useful not only in *interesting* the general public, but in giving a clear view of the present state of progress in one department of the inquiries concerning man's antiquity. If the conclusions reached are not as positive as could be wished, still it is

both desirable and important to see what degree of indefiniteness rests upon the subject, in order that rash speculations may be avoided and future investigations directed in profitable lines.

G. FREDERICK WRIGHT.

OBERLIN, OHIO, *May 1, 1892.*

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CHAPTER I.

INTRODUCTORY.

THAT glaciers now exist in the Alps, in the Scandinavian range, in Iceland, in the Himalayas, in New Zealand, in Patagonia, and in the mountains of Washington, British Columbia, and southeastern Alaska, and that a vast ice-sheet envelops Greenland and the Antarctic Continent, are statements which can be verified by any one who will take the trouble to visit those regions. That, at a comparatively recent date, these glaciers extended far beyond their present limits, and that others existed upon the highlands of Scotland and British America, and at one time covered a large part of the British Isles, the whole of British America, and a considerable area in the northern part of the United States, are inferences drawn from phenomena which are open to every one's observations. That man was in existence and occupied both Europe and America during this great expansion of the northern glaciers is proved by evidence which is now beyond dispute. It is the object of the present volume to make a concise presentation of the facts which have been rapidly accumulating during the past few years relating to the Glacial period and to its connection with human history.

Before speaking of the number and present extent of existing glaciers, it will be profitable, however, to devote a little attention to the definition of terms.

A *glacier* is a mass of ice so situated and of such size as to have motion in itself. The conditions determining the

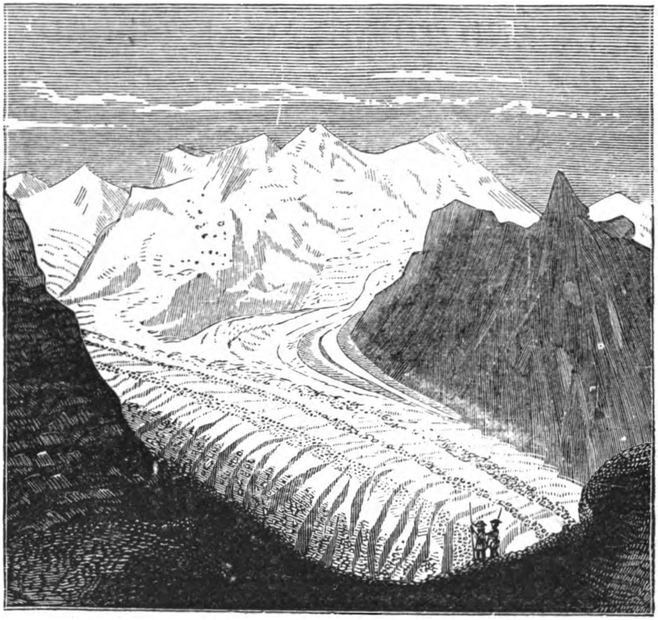


FIG. 1.—Zermatt Glacier (Agassiz).

character and rate of this motion will come up for statement and discussion later. It is sufficient here to say that ice has a capacity of movement similar to that possessed by such plastic substances as cold molasses, wax, tar, or cooling lava.

The limit of a glacier's *motion* is determined by the forces which fix the point at which its final melting takes place. This will therefore depend upon both the warmth of the weather and upon the amount of ice. If the ice is abundant, it will move farther into the region of warm temperature than it will if it is limited in supply.

Upon ascending a glacier far enough, one reaches a

motionless part corresponding to the lake out of which a river often flows. Technically this motionless part is called the *névé.*

Glacial ice is formed from snow where the annual fall is in excess of the melting power of the sun at that point. Through the influence of pressure, such as a boy applies to a snow-ball (but which in the *névé* field arises from the weight of the accumulating mass), the lower strata of the *névé* are gradually transformed into ice. This process is also assisted by the moisture which percolates through the snowy mass, and which is furnished both by the melting of the surface snow and by occasional rains.

The division between the *névé* and the glacier proper is not always easily determined. The beginnings of the glacial movement—that is, of the movement of the ice-stream flowing out of the *névé* field—are somewhat like the beginnings of the movement of the water from a great lake into its outlet. The *névé* is the reservoir from which the glacier gets both its supply of ice and the impulse which gives it its first movement. There can not be a glacier without a *névé* field, as there can not be a river without a drainage basin. But there may be a *névé* field without a glacier—that is, a basin may be partially filled with snow which never melts completely away, while the equilibrium of forces is such that the ice barely reaches to the outlet from which the tongue-like projection (to which the name glacier would be applied) fails to emerge only because of the lack of material.

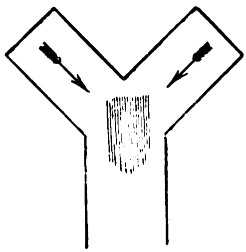


FIG. 2.—Illustrates the formation of veined structure by pressure at the junction of two branches.

A glacier is characterised by both *veins* and *fissures.* The veins give it a banded or stratified appearance, blue alternating with lighter-coloured portions of ice. As these

bands are not arranged with any apparent uniformity in the glacier, their explanation has given rise to much discussion. Sometimes the veins are horizontal, sometimes vertical, and at other times at an angle with the line of motion. On close investigation, however, it is found that the veins are always at right angles to the line of greatest pressure. This leads to the conclusion that pressure is the cause of the banded structure. The blue strata in the ice are those from which the particles of air have been expelled by pressure; the lighter portions are those in which the particles are less thoroughly compacted. Snow is but pulverized ice, and differs in colour from the compact mass for the same reason that almost all rocks and minerals change their colour when ground into a powder.

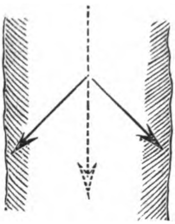


FIG. 3.

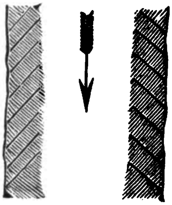


FIG. 4.

FIGS. 3, 4.—Illustrate the formation of marginal fissures and veins.

The *fissures*, which, when of large size, are called *crevasses*, are formed in those portions of a glacier where, from some cause, the ice is subjected to slight tension. This occurs especially where, through irregularities in the bottom, the slope of the descent is increased. The ice, then, instead of moving in a continuous stream at the top, cracks open along the line of tension, and wedge-shaped fissures are formed extending from the top down to a greater or less distance, according to the degree of tension. Usually, however, the ice remains continuous in the lower

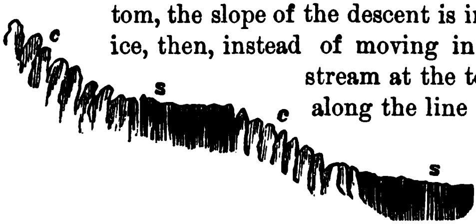


FIG. 5.—*c*, *c*, show fissures and seracs where the glacier moves down the steeper portion of its incline; *s*, *s*, show the vertical structure produced by pressure on the gentler slopes.

strata, and when the slope is diminished the pressure reunites the faces of the fissure, and the surface becomes again comparatively smooth. Where there are extensive areas of tension, the surface of the ice sometimes becomes exceedingly broken, presenting a tangled mass of towers, domes, and pinnacles of ice called *seracs.*

Like running water, moving ice is a powerful agent in *transporting* rocks and earthy *débris* of all grades of fineness; but, owing to the different consistencies of ice and water, there are great differences in the mode and result of transportation by them. While water can hold in suspension only the very finest material, ice can bear upon its surface rocks of the greatest magnitude, and can roll or shove along under it boulders and pebbles which would be unaffected except by torrential currents of water. We find, therefore, a great amount of earthy material of all sizes upon the top of a glacier, which has reached it very much as *débris* reaches the bed of a river, namely, by falling down upon it from overhanging cliffs, or by land-slides of greater or less extent. Such material coming into a river would either disappear beneath its surface, or would form a line of *débris* along the banks; in both cases awaiting the gradual erosion and transportation which running water is able to effect. But, in case of a glacier, the material rests upon the surface of the ice, and at once begins to partake of its motion, while successive accessions of material keep up the supply at any one point, so as to form a train of boulders and other *débris*, extending below the point as far as the glacial motion continues.

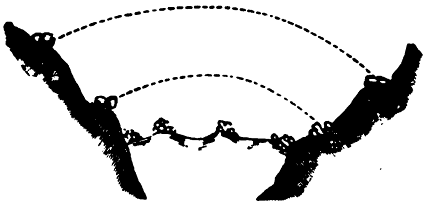


FIG. 6.—Section across Glacial Valley, showing old Lateral Moraines.

Such a line of *débris* is called a *moraine.* When it forms along the edge of the ice, it is called a *lateral* moraine. It is easy to see that, where glaciers come out from two valleys which are tributary to a larger valley, their inner sides must coalesce below the separating promontory, and the two lateral moraines will become united and will move onward in the middle of the surface of the glacier. Such lines of *débris* are called *medial* moraines. These are characteristic of all extensive glaciers formed by the union of tributaries. There is no limit to the number of medial moraines, except in the number of tributaries.

A medial moraine, when of sufficient thickness, protects the ice underneath it from melting; so that the moraine will often appear to be much larger than it really is: what seems to be a ridge of earthy material being in reality a long ridge of ice, thinly covered with earthy *débris*, sliding down the slanting sides as the ice slowly wastes away Large blocks of stone in the same manner protect the ice from melting underneath, and are found standing on pedestals of ice, often several feet in height. An interesting feature of these blocks is that, when the pedestal fails, the block uniformly falls towards the sun, since that is the side on which the melting has proceeded most rapidly.

If the meteorological forces are so balanced that the foot of a glacier remains at the same place for any great length of time, there must be a great accumulation of earthy *débris* at the stationary point, since the motion of the ice is constantly bearing its lines of lateral and medial moraine downwards to be deposited, year by year, at the melting line along the front.

Such accumulations are called *terminal* moraines, and the process of their formation may be seen at the foot of almost any large glacier. The pile of material thus confusedly heaped up in front of some of the larger glaciers of the world is enormous.

The melting away of the lower part of a glacier gives rise also to several other characteristic phenomena. Where the foot of a glacier chances to be on comparatively level land, the terminal moraine often covers a great extent of ice, and protects it from melting for an indefinite period of time. When the ice finally melts away and removes the support from the overlying morainic *débris*, this settles down in a very irregular manner, leaving enclosed depressions to which there is no natural outlet. These depressions, from their resemblance to a familiar domestic utensil, are technically known as *kettle-holes.* The terminal moraines of ancient glaciers may often be traced by the relative abundance of these kettle-holes.

The streams of water arising both from the rainfall and from the melting of the ice also produce a peculiar effect about the foot of an extensive glacier. Sometimes these streams cut long, open channels near the end of the glacier, and sweep into it vast quantities of morainic material, which is pushed along by the torrential current, and, after being abraded, rolled, and sorted, is deposited in a delta about its mouth, or left stranded in long lines between the ice-walls which have determined its course. At other times the stream has disappeared far back in the glacier, and plunged into a crevasse (technically called a *moulin*), whence it flows onwards as a subglacial stream. But in this case the deposits might closely resemble those of the previous description. In both cases, when the ice has finally melted away, peculiar ridge-like deposits of sorted material remain, to mark the temporary line of drainage. These exist abundantly in most regions which have been covered with glacial ice, and are referred to in Scotland as *kames*, in Ireland as *eskers*, and in Sweden as *osars.* In this volume we shall call them *kames*, and the deltas spread out in front of them will be referred to as *kame-plains.*

With this preliminary description of glacial phenome-

na, we will proceed to give, first, a brief enumeration and description of the ice-fields which are still existing in the world; second, the evidences of the former existence of far more extensive ice-fields; and, third, the relation of the Glacial period to some of the vicissitudes which have attended the life of man in the world.

The geological period of which we shall treat is variously designated by different writers. By some it is simply called the "post-Tertiary," or "Quaternary"; by others the term "post-Pliocene" is used, to indicate more sharply its distinction from the latter portion of the Tertiary period; by others this nicety of distinction is expressed by the term "Pleistocene." But, since the whole epoch was peculiarly characterised by the presence of glaciers, which have not even yet wholly disappeared, we may properly refer to it altogether under the descriptive name of "Glacial" period.

CHAPTER II.

EXISTING GLACIERS.

In Europe.—Our specific account of existing glaciers naturally begins with those of the Alps, where Hugi, Charpentier, Agassiz, Forbes, and Guyot, before the middle of this century, first brought clearly to light the reality and nature of glacial motion.

According to Professor Heim of Zürich, the total area covered by the glaciers and ice-fields of the Alps is upwards of three thousand square kilometres (about eleven hundred square miles). The Swiss Alps alone contain nearly two-thirds of this area. Professor Heim enumerates 1,155 distinct glaciers in the region. Of these, 144 are in France, 78 in Italy, 471 in Switzerland, and 462 in Austria.

Desor describes fourteen principal glacial districts in the Alps, the westernmost of which is that of Mont Pelvoux, in Dauphiny, and the easternmost that in the vicinity of the Gross Glockner, in Carinthia. The most important of the Alpine systems are those which are grouped around Mont Blanc, Monte Rosa, and the Finsteraarhorn, the two former peaks being upwards of fifteen thousand feet in height, and the latter upwards of fourteen thousand. The area covered by glaciers and snow-fields in the Bernese Oberland, of which Finsteraarhorn is the culminating point, is about three hundred and fifty square kilometres (a hundred square miles), and contains the Aletsch Glacier, which is the longest in Europe, extending twenty-one kilometres (about fourteen miles) from the *névé*-field

Fig. 7.—Mont Blanc Glacier Region: *m*, Mer de Glace; *g*, Du Géant; *l*, Leschaux; *t*, Taléfre; *B*, Bionassay; *b*, Bosson.

to its foot. The Mer de Glace, which descends from Mont Blanc to the valley of Chamounix, has a length of about eight miles below the *névé*-field. In all, there are estimated to be twenty-four glaciers in the Alps which are upwards of four miles long, and six which are upwards of eight miles in length. The principal of these are the Mer de Glace, of Chamounix, on Mont Blanc; the Gorner Glacier, near Zermatt, on Monte Rosa; the lower glacier of the Aar, in the Bernese Oberland; and the Aletsch Glacier and Glacier of the Rhône, in Vallais; and the Pasterzen, in Carinthia.

These glaciers adjust themselves to the width of the valleys down which they flow, in some places being a mile or more in width, and at others contracting into much narrower compass. The greatest depth which Agassiz was able directly to measure in the Aar Glacier was two hundred and sixty metres (five hundred and twenty-eight feet), but at another point the depth was estimated by him to be four hundred and sixty metres (or fifteen hundred and eighty-four feet).

The glaciers of the Alps are mostly confined to the northern side and to the higher portions of the mountain-chain, none of them descending below the level of four thousand feet, and all of them varying slightly in extent, from year to year, according as there are changes in the temperature and in the amount of snow-fall.

The Pyrenees, also, still maintain a glacial system, but it is of insignificant importance. This is partly because the altitude is much less than that of the Alps, the culminating point being scarcely more than eleven thousand feet in height. Doubtless, also, it is partly due to the narrowness of the range, which does not provide gathering-places for the snow sufficiently extensive to produce large glaciers. The snow-fall also is less upon the Pyrenees than upon the Alps. As a consequence of all these conditions, the glaciers of the Pyrenees are scarcely more

than stationary *névé*-fields lingering upon the north side of the range. The largest of these is near Baguères de Luchon, and sends down a short, river-like glacier.

In Scandinavia the height of the mountains is also much less than that of the Alps, but the moister climate and the more northern latitude favours the growth of glaciers at a much lower level North of the sixty-second degree of latitude, the plateaus over five thousand feet above the sea pretty generally are gathering-places for glaciers. From the Justedal a snow-field, covering five hundred and eighty square miles, in latitude 62°, twenty-four glaciers push outwards towards the German Sea, the largest of which is five miles long and three-quarters of a mile wide. The Fondalen snow-field, between latitudes 66° and 67°, covers an area about equal to that of the Justedal; but, on account of its more northern position, its glaciers descend through the valleys quite to the ocean-level. The Folgofon snow-field is still farther north, but, though occupying an area of only one hundred square miles, it sends down as many as three glaciers to the sea-level. The total area of the Scandinavian snow-fields is about five thousand square miles.

In Sweden Dr. Svenonius estimates that there are, between latitudes 67° and 68½°, twenty distinct groups of glaciers, covering an area of four hundred square kilometres (one hundred and forty-four square miles), and he numbers upwards of one hundred distinct glaciers of small size.

As is to be expected, the large islands in the Polar Sea north of Europe and Asia are, to a great extent, covered with *névé*-fields, and numerous glaciers push out from them to the sea in all directions, discharging their surplus ice as bergs, which float away and cumber the waters with their presence in many distant places.

The island of Spitzbergen, in latitude 76° to 81°, is favourably situated for the production of glaciers, by

reason both of its high northern latitude, and of its relation to the Gulf Stream, which conveys around to it an excessive amount of moisture, thus ensuring an excep-

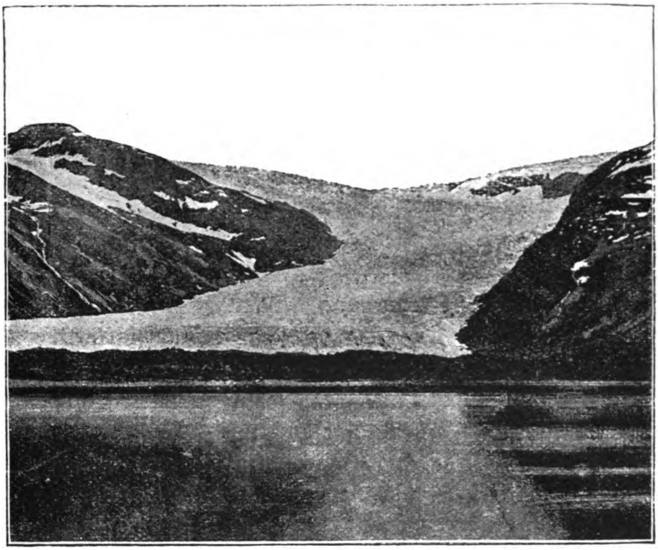


FIG. 8.—The Svartisen Glacier on the west coast of Norway, just within the Arctic circle, at the head of a fiord ten miles from the ocean. The foot of the Glacier is one mile wide, and a quarter of a mile back from the water. Terminal moraine in front. (Photographed by Dr. L. C. Warner.)

tionally large snow-fall over the island. The mountainous character of the island also favours the concentration of the ice-movement into glaciers of vast size and power. Still, even here, much of the land is free from snow and ice in summer. But upon the northern portion of the island there is an extensive table-land, upwards of two thousand feet above the sea, over which the ice-field is continuous. Four great glaciers here descend to tide-water in Magdalena Bay. The largest of these presents at the front a wall of ice seven thousand feet across and three hundred feet high; but, as the depth of the water is not

great, few icebergs of large size break off and float away from it.

Nova Zembla, though not in quite so high latitude, has a lower mean temperature upon the coasts than Spitzbergen. Owing to the absence of high lands and mountains, however, it is not covered with perpetual snow, much less with glacial ice, but its level portions are "carpeted with grasses and flowers," and sustain extensive forests of stunted trees.

Franz-Josef Land, to the north of Nova Zembla, both contains high mountains and supports glaciers of great size. Mr. Payer conducted a sledge party into this land in 1874, and reported that a precipitous wall of glacial ice, "of more than a hundred feet in height, formed the usual edge of the coast." But the motion of the ice is very slow, and the ice coarse-grained in structure, and it bears a small amount only of morainic material. So low is here the line of perpetual snow, that the smaller islands "are covered with caps of ice, so that a cross-section would exhibit a regular flat segment of ice." It is interesting to note, also, that "many ice-streams, descending from the high *névé* plateau, spread themselves out over the mountain-slopes," and are not, as in the Alps, confined to definite valleys.

Iceland seems to have been properly named, since a single one of the snow-fields—that of Vatnajoküll, with an extreme elevation of only six thousand feet—is estimated by Helland to cover one hundred and fifty Norwegian square miles (about seven thousand English square miles), while five other ice-fields (the Langjoküll, the Hofsjoküll, the Myrdalsjoküll, the Drangajoküll, and the Glamujoküll) have a combined area of ninety-two Norwegian or about four thousand five hundred English square miles. The glaciers are supposed by Whitney to have been rapidly advancing for some time past.

In Asia.—Notwithstanding its lofty mountains and its

great extent of territory lying in high latitudes, glaciers are for two reasons relatively infrequent: 1. The land in the more northern latitudes is low. 2. The dryness of the atmosphere in the interior of the continent is such that it unduly limits the snow-fall. Long before they reach the central plateau of Asia, the currents of air which sweep over the continent from the Indian Ocean have parted with their burdens of moisture, having left them in a snowy mantle upon the southern flanks of the Himalayas. As a result, we have the extensive deserts of the interior, where, on account of the clear atmosphere, there is not snow enough to resist continuously the intense activity of the unobstructed rays of the sun.

In spite of their high latitude and considerable elevation above the sea-level, glaciers are absent from the Ural Mountains, for the range is too narrow to afford *névé*-fields of sufficient size to produce glaciers of large extent.

The Caucasus Mountains present more favourable conditions, and for a distance of one hundred and twenty miles near their central portion have an average height of 12,000 feet, with individual peaks rising to a height of 16,000 feet or more; but, owing to their low latitude, the line of perpetual snow scarcely reaches down to the 11,000-foot level. So great are the snow-fields, however, above this height that many glaciers push their way down through the narrow mountain-gorges as far as the 6,000-foot level.

The Himalaya Mountains present many favourable conditions for the development of glaciers of large size. The range is of great extent and height, thus affording ample gathering-places for the snows, while the relation of the mountains to the moisture-laden winds from the Indian Ocean is such that they enjoy the first harvest of the clouds where the interior of Asia gets only the gleanings. As is to be expected, therefore, all the great rivers which course

through the plains of Hindustan have their rise in large glaciers far up towards the summits of the northern mountains. The Indus and the Ganges are both glacial streams in their origin, as are their larger tributary branches—the Basha, the Shigar, and the Sutlej. Many of the glaciers in the higher levels of the Himalaya Mountains where these streams rise have a length of from twenty-five to forty miles, and some of them are as much as a mile and a half in width and extend for a long distance, with an inclination as small as one degree and a half or one hundred and thirty-eight feet to a mile.

In the Mustagh range of the western Himalayas there are two adjoining glaciers whose united length is sixty-five miles, and another not far away which is twenty-one miles long and from one to two miles wide in its upper portion. Its lower portion terminates at an altitude of 16,000 feet above tide, where it is three miles wide and two hundred and fifty feet thick.

Oceanica.—Passing eastward to the islands of the Pacific Ocean, New Zealand is the only one capable of supporting glaciers. Their existence on this island seems the more remarkable because of its low latitude (42° to 45°); but a grand range of mountains rises abruptly from the water on the western coast of the southern island, culminating in Mount Cook, 13,000 feet above the sea, and extending for a distance of about one hundred miles. The extent and height of this chain, coupled with the moisture of the winds, which sweep without obstruction over so many leagues of the tropical Pacific, are specially favourable to the production of ice-fields of great extent. Consequently we find glaciers in abundance, some of which are not inferior in extent to the larger ones of the Alps. The Tasman Glacier, described by Haas, is ten miles long and nearly two miles broad at its termination, "the lower portion for a distance of three miles being

covered with morainic *detritus*." The Mueller Glacier is about seven miles long and one mile broad in its lower portion.

South America.—In America, existing glaciers are chiefly confined to three principal centres, namely, to the Andes, south of the equator; to the Cordilleras, north of central California; and to Greenland.

In South America, however, the high mountains of Ecuador sustain a few glaciers above the twelve-thousand-foot level. The largest of these are upon the eastern slope of the mountains, giving rise to some of the branches of the Amazon—indeed, on the flanks of Cotopaxi, Chimborazo, and Illinissa there are some glaciers in close proximity to the equator which are fairly comparable in size to those of the Alps.

In Chili, at about latitude 35°, glaciers begin to appear at lower levels, descending beyond the six-thousand-foot line, while south of this both the increasing moisture of the winds and the decreasing average temperature favour the increase of ice-fields and glaciers. Consequently, as Darwin long ago observed, the line of perpetual snow here descends to an increasingly lower level, and glaciers extend down farther and farther towards the sea, until, in Tierra del Fuego, at about latitude 45°, they begin to discharge their frozen contents directly into the tidal inlets. Darwin's party surveyed a glacier entering the Gulf of Penas in latitude 46° 50′, which was fifteen miles long, and, in one part, seven broad. At Eyre's Sound, also, in about latitude 48°, they found immense glaciers coming down to the sea and discharging icebergs of great size, one of which, as they encountered it floating outwards, was estimated to be "*at least* one hundred and sixty-eight feet in total height."

In Tierra del Fuego, where the mountains are only from three thousand to four thousand feet in height and in latitude less than 55°, Darwin reports that "every val-

ley is filled with streams of ice descending to the sea-coast," and that the inlets penetrated by his party presented miniature likenesses of the polar sea.

Antarctic Continent.—Of the so-called Antarctic Continent little is known; but icebergs of great size are frequently encountered up to 58° south latitude, in the direction of Cape Horn, and as far as latitude 33° in the direction of Cape of Good Hope. Nearly all that is known about this continent was discovered by Sir J. C. Ross

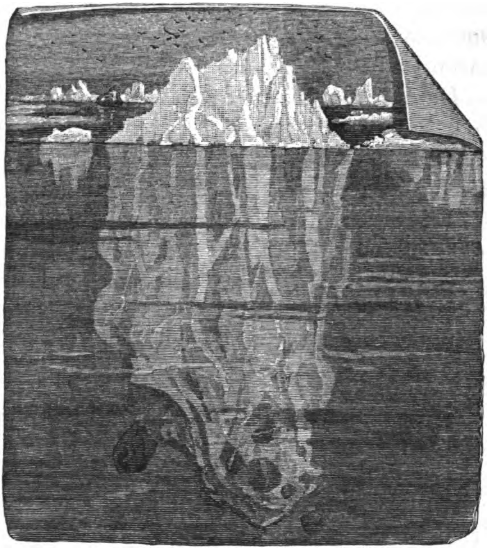


FIG. 9.—Floating berg, showing the proportions above and under the water. About seven feet under water to one above.

during the period extending from 1839 to 1843, when, between the parallels of 70° and 78° south latitude, he encountered in his explorations a precipitous mountain coast, rising from seven thousand to ten thousand feet above tide. Through the valleys intervening between the mountain-ranges huge glaciers descended, and "projected in many places several miles into the sea and terminated

in lofty, perpendicular cliffs. In a few places the rocks broke through their icy covering, by which alone we could be assured that land formed the nucleus of this, to appearance, enormous iceberg." *

Again, speaking of the region in the vicinity of the lofty volcanoes Terror and Erebus, between ten thousand and twelve thousand feet high, the same navigator says:

"We perceived a low, white line extending from its extreme eastern point, as far as the eye could discern, to the eastward. It presented an extraordinary appearance, gradually increasing in height as we got nearer to it, and proving at length to be a perpendicular cliff of ice, between one hundred and fifty and two hundred feet above the level of the sea, perfectly flat and level at the top, and without any fissures or promontories on its even, seaward face. What was beyond it we could not imagine; for, being much higher than our mast-head, we could not see anything except the summit of a lofty range of mountains extending to the southward as far as the seventy-ninth degree of latitude. These mountains, being the southernmost land hitherto discovered, I felt great satisfaction in naming after Sir Edward Parry. . . . Whether Parry Mountains again take an easterly trending and form the base to which this extraordinary mass of ice is attached, must be left for future navigators to determine. If there be land to the southward it must be very remote, or of much less elevation than any other part of the coast we have seen, or it would have appeared above the barrier."

This ice-cliff or barrier was followed by Captain Ross as far as 198° west longitude, and found to preserve very much the same character during the whole of that distance. On the lithographic view of this great ice-sheet given in Ross's work it is described as "part of the South Polar Barrier, one hundred and eighty feet above the sea-

* Quoted by Whitney in Climatic Changes, p. 314.

level, one thousand feet thick, and four hundred and fifty miles in length."

A similar vertical wall of ice was seen by D'Urville, off the coast of Adelie Land. He thus describes it: "Its appearance was astonishing. We perceived a cliff having a uniform elevation of from one hundred to one hundred and fifty feet, forming a long line extending off to the west. . . . Thus for more than twelve hours we had followed this wall of ice, and found its sides everywhere perfectly vertical and its summit horizontal. Not the smallest irregularity, not the most inconsiderable elevation, broke its uniformity for the twenty leagues of distance which we followed it during the day, although we passed it occasionally at a distance of only two or three miles, so that we could make out with ease its smallest irregularities. Some large pieces of ice were lying along the side of this frozen coast; but, on the whole, there was open sea in the offing." *

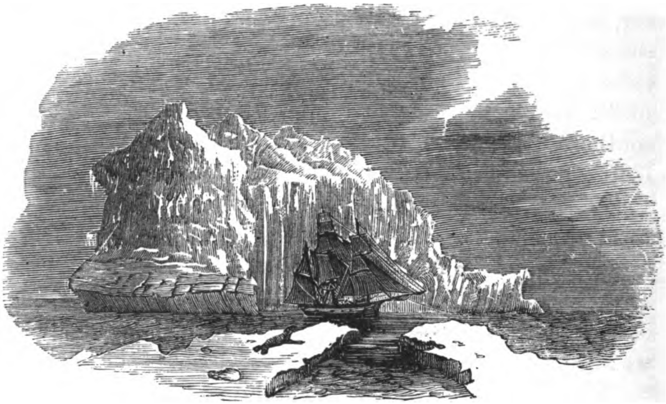


FIG. 10.—Iceberg in the Antarctic Ocean.

North America.—In North America living glaciers

* Whitney's Climatic Changes, pp. 315, 316.

begin to appear in the Sierra Nevada Mountains, in the vicinity of the Yosemite Park, in central California. Here the conditions necessary for the production of glaciers are favourable, namely, a high altitude, snow-fields of considerable extent, and unobstructed exposure to the moisture-laden currents of air from the Pacific Ocean. Sixteen glaciers of small size have been noted among the summits to the east of the Yosemite; but none of them descend much below the eleven-thousand-foot line, and none of them are over a mile in length. Indeed, they are so small, and their motion is so slight, that it is a question whether or not they are to be classed with true glaciers.

Owing to the comparatively low elevation of the Sierra Nevada north of Tuolumne County, California, no other living glaciers are found until reaching Mount Shasta, in the extreme northern part of the State. This is a volcanic peak, rising fourteen thousand five hundred feet above the sea, and having no peaks within forty miles of it as high as ten thousand feet; yet so abundant is the snow-fall that as many as five glaciers are found upon its northern side, some of them being as much as three miles long and extending as low down as the eight-thousand-foot level. Upon the southern side glaciers are so completely absent that Professor Whitney ascended the mountain and remained in perfect ignorance of its glacial system. In 1870 Mr. Clarence King first discovered and described them on the northern side.

North of California glaciers characterise the Cascade Range in increasing numbers all the way to the Alaskan Peninsula. They are to be found upon Diamond Peak, the Three Sisters, Mount Jefferson, and Mount Hood, in Oregon, and appear in still larger proportions upon the flanks of Mount Rainier (or Tacoma) and Mount Baker, in the State of Washington. The glacier at the head of the White River Valley is upon the north side of Rainier, and is the largest one upon that mountain, reaching

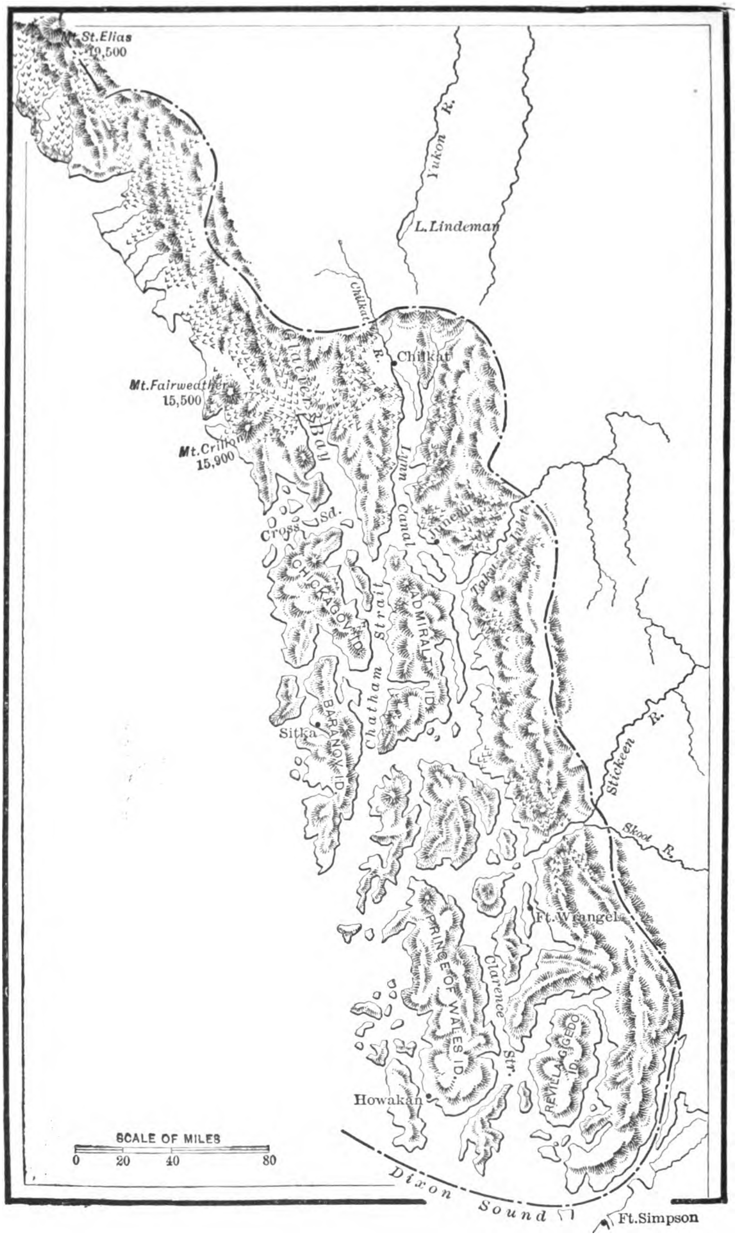


FIG. 11.—Map of Southeastern Alaska. The arrow-points mark glaciers.

down to within five thousand feet of the sea-level, and being ten miles or more in length. All the streams which descend the valleys upon this mountain are charged with the milky-coloured water which betrays their glacial origin.

In British Columbia, Glacier Station, upon the Canadian Pacific Railroad, in the Selkirk Mountains, is within half a mile of the handsome Illicilliwaet Glacier, while others of larger size are found at no great distance. The interior farther north is unexplored to so great an extent that little can be definitely said concerning its glacial phenomena. The coast of British Columbia is penetrated by numerous fiords, each of which receives the drainage of a decaying glacier; but none are in sight of the tourist-steamers which thread their way through the intricate network of channels characterising this coast, until the Alaskan boundary is crossed and the mouth of the Stickeen River is passed.

A few miles up from the mouth of the Stickeen, however, glaciers of large size come down to the vicinity of the river, both from the north and from the south, and the attention of tourists is always attracted by the abundant glacial sediment borne into the tide-water by the river itself and discolouring the surface for a long distance beyond the outlet. Northward from this point the tourist is rarely out of sight of ice-fields. The Auk and Patterson Glaciers are the first to come into view, but they do not descend to the water-level. On nearing Holcomb Bay, however, small icebergs begin to appear, heralding the first of the glaciers which descend beyond the water's edge. Taku Inlet, a little farther north, presents glaciers of great size coming down to the sea-level, while the whole length of Lynn Canal, from Juneau to Chilkat, a distance of eighty miles, is dotted on both sides by conspicuous glaciers and ice-fields.

The Davidson Glacier, near the head of the canal, is one of the most interesting for purposes of study. It

comes down from an unknown distance in the western interior, bearing two marked medial moraines upon its surface. On nearing tide-level, the valley through which it flows is about three-quarters of a mile in width; but, after emerging from the confinement of the valley, the ice spreads out over a fan-shaped area until the width of its front is nearly three miles. The supply of ice not being sufficient to push the front of the glacier into deep water, equilibrium between the forces of heat and cold is established near the water's edge. Here, as from year to year the ice melts and deposits its burdens of earthy *débris*, it has piled up a terminal moraine which rises from two hundred to three hundred feet in height, and is now covered with evergreen trees of considerable size. From Chilkat, at the head of Lynn Canal, to the sources of the Yukon River, the distance is only thirty-five miles, but the intervening mountain-chain is several thousand feet in height and bears numerous glaciers upon its seaward side.

About forty miles west of Lynn Canal, and separated from it by a range of mountains of moderate height, is Glacier Bay, at the head of one of whose inlets is the Muir Glacier, which forms the chief attraction for the great number of tourists that now visit the coast of southeastern Alaska during the summer season. This glacier meets tide-water in latitude 58° 50′, and longitude 136° 40′ west of Greenwich. It received its name from Mr. John Muir, who, in company with Rev. Mr. Young, made a tour of the bay and discovered the glacier in 1879. It was soon found that the bay could be safely navigated by vessels of large size, and from that time on tourists in increasing number have been attracted to the region. Commodious steamers now regularly run close up to the ice-front, and lie-to for several hours, so that the passengers may witness the "calving" of icebergs, and may climb upon the sides of the icy stream and look into its

deep crevasses and out upon its corrugated and broken surface.

The first persons who found it in their way to pay more than a tourist's visit to this interesting object were

Fig. 12.—Map of Glacier Bay, Alaska, and its surroundings. Arrow-points indicate glaciated area.

Rev. J. L. Patton, Mr. Prentiss Baldwin, and myself, who spent the entire month of August, 1886, encamped at the

foot of the glacier, conducting such observations upon it as weather and equipment permitted. From that time

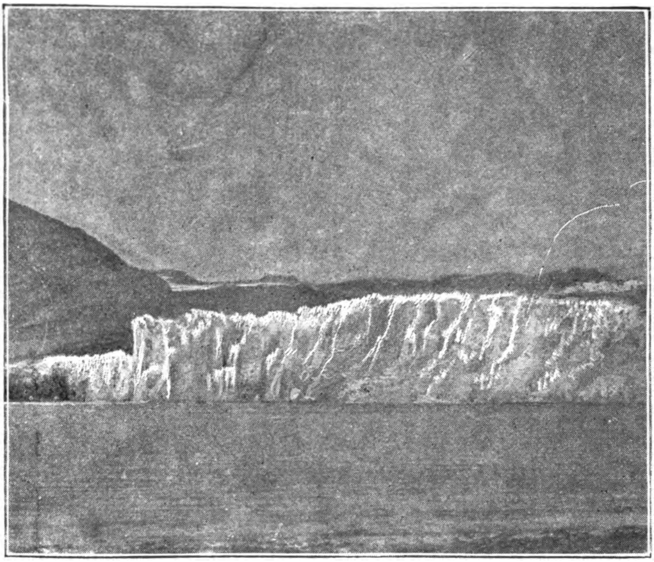


FIG. 13.—Shows central part of the front of Muir Glacier one half mile distant. Near the lower left hand corner the ice is seen one mile distant resting for about one half mile on gravel which it had overrun. The ice is now retreating in the channel. (From photograph.)

till the summer of 1890 no one else stopped off from the tourist steamers to bestow any special study upon it. But during this latter season Mr. Muir returned to the scene of his discovered wonder, and spent some weeks in exploring the interior of the great ice-field. During the same season, also, Professors H. F. Reid and H. Cushing, with a well-equipped party of young men, spent two months or more in the same field, conducting observations and experiments, of various kinds, relating to the extent, the motion, and the general behaviour of the vast mass of moving ice.

The main body of the Muir Glacier occupies a vast

amphitheatre, with diameters ranging from thirty to forty miles, and covers an area of about one thousand square miles. From one of the low mountains near its mouth I could count twenty-six tributary glaciers which came together and became confluent in the main stream of ice. Nine medial moraines marked the continued course of as many main branches, which becoming united formed the grand trunk of the glacier. Numerous rocky eminences also projected above the surface of the ice, like islands in the sea, corresponding to what are called "*nunataks*" in Greenland. The force of the ice against the upper side of these rocky prominences is such as to push it in great masses above the surrounding level, after the analogy of waves which dash themselves into foam against similar obstructions. In front of the *nunataks* there is uniformly a depression, like the eddies which appear in the current below obstacles in running water.

Over some portions of the surface of the glacier there is a miniature river system, consisting of a main stream, with numerous tributaries, but all flowing in channels of deep blue ice. Before reaching the front of the glacier, however, each one of these plunges down into a crevasse, or *moulin*, to swell the larger current, which may be heard rushing along in an impetuous course hundreds of feet beneath, and far out of sight. The portion of the glacier in which there is the most rapid motion is characterised by innumerable crags and domes and pinnacles of ice, projecting above the general level, whose bases are separated by fissures, extending in many cases more than a hundred feet below the general level. These irregularities result from the combined effect of the differential motion (as illustrated in the diagram on page 4), and the influence of sunshine and warm air in irregularly melting the unprotected masses. The description given in our introductory chapter of medial moraines and ice-pillars is amply illustrated everywhere upon the surface

of the Muir Glacier. I measured one block of stone which was twenty feet square and about the same height, standing on a pedestal of ice three or four feet high.

The mountains forming the periphery of this amphitheatre rise to a height of several thousand feet; Mount Fairweather, upon the northwest, from whose flanks probably a portion of the ice comes, being, in fact, more than fifteen thousand feet high. The mouth of the amphitheatre is three miles wide, in a line extending from shoulder to shoulder of the low mountains which guard it. The actual water-front where the ice meets tide-water is one mile and a half.* Here the depth of the inlet is so great that the front of the ice breaks off in icebergs of large size, which float away to be dissolved at their leisure. At the water's edge the ice presents a perpendicular front of from two hundred and fifty to four hundred feet in height, and the depth of the water in the middle of the inlet immediately in front of the ice is upwards of seven hundred feet; thus giving a total height to the precipitous front of a thousand feet.

The formation of icebergs can here be studied to admirable advantage. During the month in which we encamped in the vicinity the process was going on continuously. There was scarcely an interval of fifteen minutes during the whole time in which the air was not rent with the significant boom connected with the "calving" of a berg. Sometimes this was occasioned by the separation of a comparatively small mass of ice from near the top of the precipitous wall, which would fall into the water below with a loud splash. At other times I have seen a column of ice from top to bottom of the precipice split off and fall over into the water, giving rise to great waves, which would lash the shore with foam two miles below.

* These are the measurements of Professor Reid. In my former volume I have given the dimensions as somewhat smaller.

This manner of the production of icebergs differs from that which has been ordinarily represented in the text-books, but it conforms to the law of glacial motion, which we will describe a little later, namely, that the upper strata of ice move faster than the lower. Hence the tendency is constantly to push the upper strata forwards, so as to produce a perpendicular or even projecting front, after the analogy of the formation of breakers on the shelving shore of a large body of water.

Evidently, however, these masses of ice which break off from above the water do not reach the whole distance to the bottom of the glacier below the water; so that a projecting foot of ice remains extending to an indefinite distance underneath the surface. But at occasional intervals, as the superincumbent masses of ice above the surface fall off and relieve the strata below of their weight, these submerged masses suddenly rise, often shooting up considerably higher than they ultimately remain when coming to rest. The bergs formed by this latter process often bear much earthy material upon them, which is carried away with the floating ice, to be deposited finally wherever the melting chances to take place.

Numerous opportunities are furnished about the front and foot of this vast glacier to observe the manner of the formation of *kames*, kettle-holes, and various other irregular forms into which glacial *débris* is accustomed to accumulate. Over portions of the decaying foot of the glacier, which was deeply covered with morainic *débris*, the supporting ice is being gradually removed through the influence of subglacial streams or of abandoned tunnels, which permit the air to exert its melting power underneath. In some places where old *moulins* had existed, the supporting ice is melting away, so that the superincumbent mass of sand, gravel, and boulders is slowly sliding into a common centre, like grain in a hopper. This must produce a conical hill, to remain, after the ice has all melted

away, a mute witness of the impressive and complicated forces which have been so long in operation for its production.

In other places I have witnessed the formation of a long ridge of gravel by the gradual falling in of the roof of a tunnel which had been occupied by a subglacial stream, and over which there was deposited a great amount of morainic material. As the roof gave way, this was constantly falling to the bottom, where, being exempt from further erosive agencies, it must remain as a gravel ridge or kame.

In other places, still, there were vast masses of ice covering many acres, and buried beneath a great depth of morainic material which had been swept down upon it while joined to the main glacier. In the retreat of the ice, however, these masses had become isolated, and the sand, gravel, and boulders were sliding down the wasting sides and forming long ridges of *débris* along the bottom, which, upon the final melting of the ice, will be left as a complicated network of ridges and knolls of gravel, enclosing an equally complicated nest of kettle-holes.

Beyond Cross Sound the Pacific coast is bounded for several hundred miles by the magnificent semicircle of mountains known as the St. Elias Alps, with Mount Crillon at the south, having an elevation of nearly sixteen thousand feet, and St. Elias in the centre, rising to a greater height. Everywhere along this coast, as far as the Alaskan Peninsula, vast glaciers come down from the mountain-sides, and in many cases their precipitous fronts form the shore-line for many miles at a time. Icy Bay, just to the south of Mount St. Elias, is fitly named, on account of the extent of the glaciers emptying into it and the number of icebergs cumbering its waters.

In the summer of 1890 a party, under the lead of Mr. I. C. Russell, of the United States Geological Survey, made an unsuccessful attempt to scale the heights of

Mount St. Elias; but the information brought back by them concerning the glaciers of the region amply repaid

FIG. 14.—By the courtesy of the National Geographical Society.

them for their toil and expense, and consoled them for the failure of their immediate object.

Leaving Yakutat Bay, and following the route indicated upon the accompanying map, they travelled on glacial ice almost the entire distance to the foot of Mount St. Elias. The numerous glaciers coming down from the summit of the mountain-ridge become confluent nearer the shore, and spread out over an area of about a thousand square miles. This is fitly named the Malaspina Glacier, after the Spanish explorer who discovered it in 1792.

It is not necessary to add further particulars concern-

ing the results of this expedition, since they are so similar to those already detailed in connection with the Muir Glacier. A feature, however, of special interest, pertains to the glacial lakes which are held in place by the glacial ice at an elevation of thousands of feet above the sea. One of considerable size is indicated upon the map just south of what was called Blossom Island, which, however, is not an island, but simply a *nunatak*, the ice here surrounding a considerable area of fertile land, which is covered with dense forests and beautified by a brilliant assemblage of flowering plants. In other places considerable vegetation was found upon the surface of moraines, which were probably still in motion with the underlying ice.

Greenland.—The continental proportions of Greenland, and the extent to which its area is covered by glacial ice, make it by far the most important accessible field for glacial observations. The total area of Greenland can not be less than five hundred thousand square miles—equal in extent to the portion of the United States east of the Mississippi and north of the Ohio. It is now pretty evident that the whole of this area, except a narrow border about the southern end, is covered by one continuous sheet of moving ice, pressing outward on every side towards the open water of the surrounding seas.

For a long time it was the belief of many that a large region in the interior of Greenland was free from ice, and was perhaps inhabited. It was in part to solve this problem that Baron Nordenskiöld set out upon his expedition of 1883. Ascending the ice-sheet from Disco Bay, in latitude 69°, he proceeded eastward for eighteen days across a continuous ice-field. Rivers were flowing in channels upon the surface like those cut on land in horizontal strata of shale or sandstone, only that the pure deep blue of the ice-walls was, by comparison, infinitely more beautiful. These rivers were not, however, perfectly continuous. After flowing for a distance in channels on the

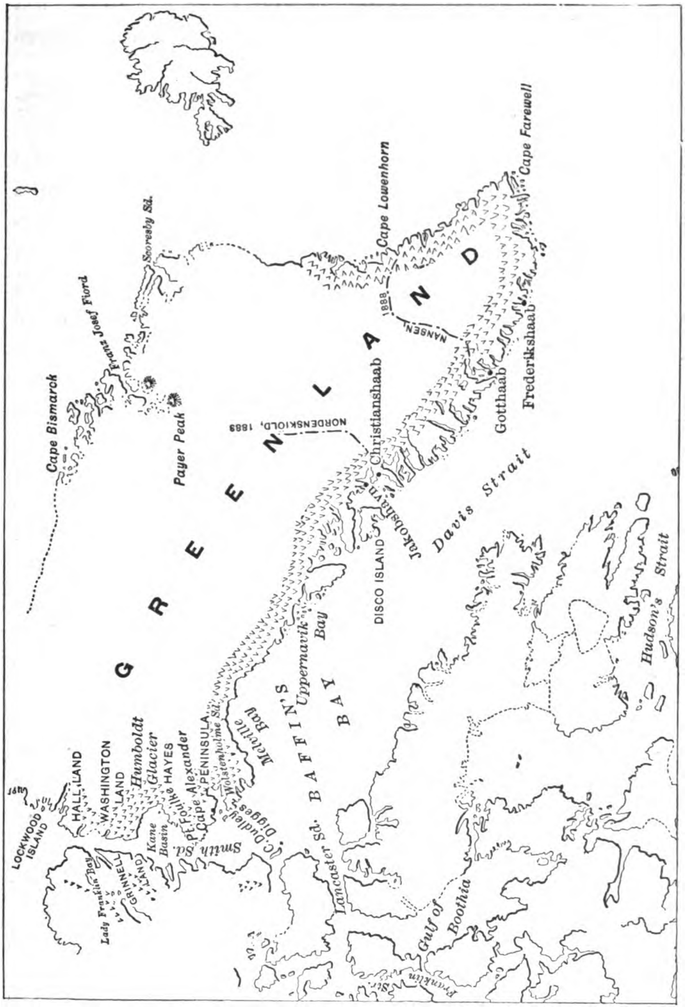


Fig. 15.—Map of Greenland. The arrow-points mark the margin of the ice-field.

surface, they, one and all, plunged with deafening roar into some yawning crevasse, to find their way to the sea through subglacial channels. Numerous lakes with shores of ice were also encountered.

"On bending down the ear to the ice," says this explorer, "we could hear on every side a peculiar subterranean hum, proceeding from rivers flowing within the ice; and occasionally a loud, single report, like that of a cannon, gave notice of the formation of a new glacier-cleft. . . . In the afternoon we saw at some distance from us a well-defined pillar of mist, which, when we approached it, appeared to rise from a bottomless abyss, into which a mighty glacier-river fell. The vast, roaring water-mass had bored for itself a vertical hole, probably down to the rock, certainly more than two thousand feet beneath, on which the glacier rested." *

At the end of the eighteen days Nordenskiöld found himself about a hundred and fifty miles from his starting-point, and about five thousand feet above the sea. Here the party rested, and sent two Eskimos forward on *skidor*—a kind of long wooden skate, with which they could move rapidly over the ice, notwithstanding the numerous small, circular holes which everywhere pitted the surface. These Eskimos were gone fifty-seven hours, having slept only four hours of the period. It is estimated that they made about a hundred and fifty miles, and attained an altitude of six thousand feet. The ice is reported as rising in distinct terraces, and as seemingly boundless beyond. If this is the case, two hundred miles from Disco Bay, there would seem little hope of finding in Greenland an interior freed from ice. So we may pretty confidently speak of that continental body of land as still enveloped in an ice-sheet. Up to about latitude 75°, however, the continent is fringed by a border of islands, over which

* Geological Magazine, vol. ix, pp. 393, 399.

there is no continuous covering of ice. In south Greenland the continuous ice-sheet is reached about thirty miles back from the shore.

A summary of the results of Greenland exploration was given by Dr. Rink in 1886, from which it appears that since 1876 one thousand miles of the coast-line have been carefully explored by entering every fiord and attempting to reach the inland ice. According to this authority—

We are now able to demonstrate that a movement of ice from the central regions of Greenland to the coast continually goes on, and must be supposed to act upon the ground over which it is pushed so as to detach and transport fragments of it for such a distance. . . . The plainest idea of the ice-formation here in question is given by comparing it with an inundation. . . . Only the marginal parts show irregularity; towards the interior the surface grows more and more level and passes into a plain very slightly rising in the same direction. It has been proved that, ascending its extreme verge, where it has spread like a lava-stream over the lower ground in front of it, the irregularities are chiefly met with up to a height of 2,000 feet, but the distance from the margin in which the height is reached varies much. While under 68½° north latitude it took twenty-four miles before this elevation was attained, in 72½° the same height was arrived at in half the distance. . . .

A general movement of the whole mass from the central regions towards the sea is still continued, but it concentrates its force to comparatively few points in the most extraordinary degree. These points are represented by the ice-fiords, through which the annual surplus ice is carried off in the shape of bergs. . . . In Danish Greenland are found five of the first, four of the second, and eight of the third (or least productive) class, besides a number of inlets which only receive insignificant frag-

3

ments. Direct measurements of the velocity have now been applied on three first-rate and one second-rate fiords, all situated between 69° and 71° north latitude. The measurements have been repeated during the coldest and the warmest season, and connected with surveying and other investigations of the inlets and their environs. It is now proved that the glacier branches which produce the bergs proceed incessantly at a rate of thirty to fifty feet per diem, this movement being not at all influenced by the seasons. . . .

In the ice-fiord of Jakobshavn, which spreads its enormous bergs over Disco Bay and probably far into the Atlantic, the productive part of the glacier is 4,500 metres (about 2½ miles) broad. The movement along its middle line, which is quicker than on the sides nearer the shores, can be rated at fifty feet per diem. The bulk of ice here annually forced into the sea would, if taken on the shore, make a mountain two miles long, two miles broad, and 1,000 feet high. The ice-fiord of Torsukatak receives four or five branches of the glacier; the most productive of them is about 9,000 metres broad (five miles), and moves between sixteen and thirty-two feet per diem. The large Karajak Glacier, about 7,000 metres (four miles) broad, proceeds at a rate of from twenty-two to thirty-eight feet per diem. Finally, a glacier branch dipping into the fiord of Jtivdliarsuk, 5,800 metres broad (three miles), moved between twenty-four and forty-six feet per diem.*

The principal part of our information concerning the glaciers of Greenland north of Melville Bay was obtained by Drs. Kane and Hayes, in 1853 and 1854, while conducting an expedition in search of Sir John Franklin and his unfortunate crew. Dr. Hayes conducted another ex-

* See Transactions of the Edinburgh Geological Society for February 18, 1886, vol. v, part ii, pp. 286–293.

pedition to the same desolate region in 1860, while other explorers have to some extent supplemented their observations. The largest glacier which they saw enters the sea between latitude 79° and 80°, where it presents a precipitous discharging front more than sixty miles in width and hundreds of feet in perpendicular height.

Dr. Kane gives his first impressions of this grand glacier in the following vivid description:

"I will not attempt to do better by florid description. Men only rhapsodize about Niagara and the ocean. My notes speak simply of the 'long, ever-shining line of cliff diminished to a well-pointed wedge in the perspective'; and, again, of 'the face of glistening ice, sweeping in a long curve from the low interior, the facets in front intensely illuminated by the sun.' But this line of cliff rose in a solid, glassy wall three hundred feet above the water-level, with an unknown, unfathomable depth below it; and its curved face, sixty miles in length from Cape Agassiz to Cape Forbes, vanished into unknown space at not more than a single day's railroad-travel from the pole. The interior, with which it communicated and from which it issued, was an unsurveyed *mer de glace*—an ice-ocean to the eye, of boundless dimensions.

"It was in full sight—the mighty crystal bridge which connects the two continents of America and Greenland. I say continents, for Greenland, however insulated it may ultimately prove to be, is in mass strictly continental. Its least possible axis, measured from Cape Farewell to the line of this glacier, in the neighbourhood of the eightieth parallel, gives a length of more than 1,200 miles, not materially less than that of Australia from its northern to its southern cape.

"Imagine, now, the centre of such a continent, occupied through nearly its whole extent by a deep, unbroken sea of ice that gathers perennial increase from the watershed of vast snow-covered mountains and all the precipi-

tations of its atmosphere upon its own surface. Imagine this, moving onwards like a great glacial river, seeking outlets at every fiord and valley, rolling icy cataracts into the Atlantic and Greenland seas; and, having at last reached the northern limit of the land that has borne it up, pouring out a mighty frozen torrent into unknown arctic space!

"It is thus, and only thus, that we must form a just conception of a phenomenon like this great glacier. I had looked in my own mind for such an appearance, should I ever be fortunate enough to reach the northern coast of Greenland; but, now that it was before me, I could hardly realize it. I had recognized, in my quiet library at home, the beautiful analogies which Forbes and Studer have developed between the glacier and the river. But I could not comprehend at first this complete substitution of ice for water.

"It was slowly that the conviction dawned on me that I was looking upon the counterpart of the great river-system of Arctic Asia and America. Yet here were no water-feeders from the south. Every particle of moisture had its origin within the polar circle and had been converted into ice. There were no vast alluvions, no forest or animal traces borne down by liquid torrents. Here was a plastic, moving, semi-solid mass, obliterating life, swallowing rocks and islands, and ploughing its way with irresistible march through the crust of an investing sea."*

Much less is known concerning the eastern coast of Greenland than about the western coast. For a long time it was supposed that there might be a considerable population in the lower latitudes along the eastern side. But that is now proved to be a mistake. The whole coast is very inhospitable and difficult of approach. From lati-

* See Transactions of the Edinburgh Geological Society for February 18, 1886, vol. v, part ii, pp. 225–228.

tude 65° to latitude 69° little or nothing is known of it. In 1822–'23 Scoresby, Cleavering, and Sabine hastily explored the coast from latitude 69° to 76°, and reported numerous glaciers descending to the sea-level through extensive fiords, from which immense icebergs float out and render navigation dangerous. In 1869 and 1870 the second North-German Expedition partly explored the coast between latitude 73° and 77°. Mr. Payer, an experienced Alpine explorer, who accompanied the expedition, reports the country as much broken, and the glaciers as "subordinated in position to the higher peaks, and having their moraines, both lateral and terminal, like those of the Alpine ranges, and on a still grander scale." Petermann Peak, in latitude 73°, is reported as 13,000 feet high. Captain Koldewey, chief of the expedition, found extensive plateaus on the mainland, in latitude 75°, to be "entirely clear of snow, although only sparsely covered with vegetation." The mountains in this vicinity, also, rising to a height of more than 2,000 feet, were free from snow in the summer. Some of the fiords in this vicinity penetrate the continent through several degrees of longitude.

An interesting episode of this expedition was the experience of the crew of the ship Hansa, which was caught in the ice and destroyed. The crew, however, escaped by encamping on the ice-floe which had crushed the ship. From this, as it slowly floated towards the south through several degrees of latitude, they had opportunity to make many important observations upon the continent itself. As viewed from this unique position the coast had the appearance everywhere of being precipitous, with mountains of considerable height rising in the background, from which numerous small glaciers descended to the sea-level.

In 1888 Dr. F. Nansen, with Lieutenant Sverdrup and four others, was left by a whaler on the ice-pack bordering the east of Greenland about latitude 65°, and in sight of the coast. For twelve days the party was on the ice-

pack floating south, and so actually reached the coast only about latitude 64°. From this point they attempted to cross the inland ice in a northwesterly direction towards Christianshaab. They soon reached a height of 7,000 feet, and were compelled by severe northerly storms to diverge from their course, taking a direction more to the west. The greatest height attained was 9,500 feet, and the party arrived on the western coast at Ameralik Fiord, a little south of Godhaab, about the same latitude at which they entered.

It thus appears that subsequent investigations have confirmed in a remarkable manner the sagacious conclusions made by the eminent Scotch geologist and glacialist Robert Brown in 1875, soon after his own expedition to the country. "I look upon Greenland and its interior ice-field," he writes, "in the light of a broad-lipped, shallow vessel, but with chinks in the lips here and there, and the glacier like viscous matter in it. As more is poured in, the viscous matter will run over the edges, naturally taking the line of the chinks as its line of outflow. The broad lips of the vessel are the outlying islands or 'outskirts'; the viscous matter in the vessel the inland ice, the additional matter continually being poured in in the form of the enormous snow covering, which, winter after winter, for seven or eight months in the year, falls almost continuously on it; the chinks are the fiords or valleys down which the glaciers, representing the outflowing viscous matter, empty the surplus of the vessel—in other words, the ice floats out in glaciers, overflows the land in fact, down the valleys and fiords of Greenland by force of the superincumbent weight of snow, just as does the grain on the floor of a barn (as admirably described by Mr. Jamieson) when another sackful is emptied on the top of the mound already on the floor. 'The floor is flat, and therefore does not conduct the grain in any direction; the outward motion is due to the pressure

of the particles of grain on one another; and, given a floor of infinite extension and a pile of sufficient amount, the mass would move outward to any distance, and with a very slight pitch or slope it would slide forward along the incline.' To this let me add that if the floor on the margin of the heap of grain was undulating the stream of grain would take the course of such undulations. The want, therefore, of much slope in a country and the absence of any great mountain-range are of very little moment to the movement of land-ice, *provided we have snow enough*." On another page Dr. Brown had well said that "the country seems only a circlet of islands separated from one another by deep fiords or straits, and bound together on the landward side by the great ice covering which overlies the whole interior. . . . No doubt under this ice there lies land, just as it lies under the sea; but nowadays none can be seen, and as an insulating medium it might as well be water."

In his recently published volumes descriptive of the journey across the Greenland ice-sheet, alluded to on page 39, Dr. Nansen sums up his inferences in very much the same way: "The ice-sheet rises comparatively abruptly from the sea on both sides, but more especially on the east coast, while its central portion is tolerably flat. On the whole, the gradient decreases the farther one gets into the interior, and the mass thus presents the form of a shield with a surface corrugated by gentle, almost imperceptible, undulations lying more or less north and south, and with its highest point not placed symmetrically, but very decidedly nearer the east coast than the west."

From this rapid glance at the existing glaciers of the world we see that a great ice age is not altogether a strange thing in the world. The land about the south pole and Greenland are each continental in dimensions, and present at the present time accumulations of land-ice so extensive, so deep, and so alive with motion as to pre-

pare our minds for almost anything that may be suggested concerning the glaciated condition of other portions of the earth's surface. The *vera causa* is sufficient to accomplish anything of which glacialists have ever dreamed. It only remains to enquire what the facts really are and over how great an extent of territory the actual results of glacial action may be found. But we will first direct more particular attention to some of the facts and theories concerning glacial motion.

CHAPTER III.

GLACIAL MOTION.

THAT glacial ice actually moves after the analogy of a semi-fluid has been abundantly demonstrated by observation. In the year 1827. Professor Hugi, of Soleure, built a hut far up upon the Aar Glacier in Switzerland, in order to determine the rate of its motion. After three years he found that it had moved 330 feet; after nine years, 2,354 feet; and after fourteen years Louis Agassiz found that its motion had been 4,712 feet. In 1841 Agassiz began a more accurate series of observation upon the same glacier. Boring holes in the ice, he set across it a row of stakes which, on visiting in 1842, he found to be no longer in a straight line. All had moved downwards with varying velocity, those near the centre having moved farther than the others. The displacements of the stakes were in order, from side to side, as follows: 160 feet, 225 feet, 269 feet, 245 feet, 210 feet, and 125 feet. Agassiz followed up his observations for six years, and in 1847 published the results in his celebrated work System Glacière.

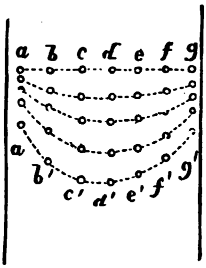


FIG. 16.

But in August, 1841, the distinguished Swiss investigator had invited Professor J. D. Forbes, of Edinburgh, to interest himself in solving the problem of glacial motion. In response to this request, Professor Forbes spent three weeks with Agassiz upon the Aar Glacier. Stimulated

by the interest of this visit, Forbes returned to Switzerland in 1842 and began a series of independent investigations upon the Mer de Glace. After a week's observations with accurate instruments, Forbes wrote to Professor Jameson, editor of the Edinburgh New Philosophical Journal, that he had already made it certain that "the central part of the glacier moves faster than the edges in a very considerable proportion, quite contrary to the opinion generally maintained." This letter was dated July 4, 1842, but was not published until the October following. Agassiz's results, so far as then determined, were, however, published in Comptes Rendus of the 29th of August, 1842, two months before the publication of Forbes's letter. But Agassiz's letter was dated twenty-seven days later than that of Forbes. It becomes certain, therefore, that both Agassiz and Forbes, independently and about the same time, discovered the fact that the central portion of a glacier moves more rapidly than the sides.

In 1857 Professor Tyndall began his systematic and fruitful observations upon the Mer de Glace and other Alpine glaciers. Professor Forbes had already demonstrated that, with an accurate instrument of observation, the motion of a line of stakes might be observed after the lapse of a single day, or even of a few hours. As a result of Tyndall's observations, it was found that the most rapid daily motion in the Mer de Glace in 1857 was about thirty-seven inches. This amount of motion was near the lower end of the glacier On ascending the glacier, the rate was found in general to be diminished; but the diminution was not uniform throughout the whole distance, being affected both by the size and by the contour of the valley. The motion in the tributary glaciers was also much less than that of the main glacier.

This diminution of movement in the tributary glaciers was somewhat proportionate to their increase in width.

For example, the combined width of the three tributaries uniting to form the Mer de Glace is 2,597 yards; but a short distance below the junction of these tributaries the total width of the Mer de Glace itself is only 893 yards, or one-third that of the tributaries combined. Yet, though the depth of the ice is probably here much greater than in the tributaries, the rapidity of movement is between two and three times as great as that of any one of the branches.*

From Tyndall's observations it appears also that the line of most rapid motion is not exactly in the middle of the channel, but is pushed by its own momentum from one side to the other of the middle, so as always to be nearer the concave side; in this respect conforming, as far as its nature will permit, to the motion of water in a tortuous channel.

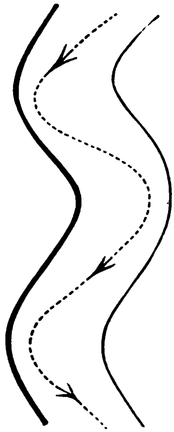


FIG. 17.

It is easy to account for this differential motion upon the surface of a glacier, since it is clear that the friction of the sides of the channel must retard the motion of ice as it does that of water. It is clear also that the friction of the bottom must retard the motion of ice even more than it is known to do in the case of water. In the formation of breakers, when the waves roll in upon a shallowing beach, every one is familiar with the effect of the bottom upon the moving mass. Here friction retards the lower strata of water, and the upper strata slide over the lower, and, where the water is of sufficient depth and the motion is sufficiently great, the crest breaks down in foam before the ever-advancing tide. A similar phenomenon occurs when dams give way and reservoirs suddenly pour their contents into the restricted channels

* See Tyndall's Forms of Water, pp. 78–82.

below. At such times the advancing water rolls onwards like the surf with a perpendicular front, varying in height according to the extent of the flood.

Reasoning from these phenomena connected with moving water, it was naturally suggested to Professor Tyndall that an analogous movement must take place in a glacier. Choosing, therefore, a favourable place for observation on the Mer de Glace where the ice emerged from a gorge, he found a perpendicular side about one hundred and fifty feet in height from bottom to top. In this face he drove stakes in a perpendicular line from top to bottom. Upon subsequently observing them, Tyndall found, as he expected, that there was a differential motion among them as in the stakes upon the surface. The retarding effect of friction upon the bottom was evident. The stake near the top moved forwards about three times as fast as the one which was only four feet from the bottom.

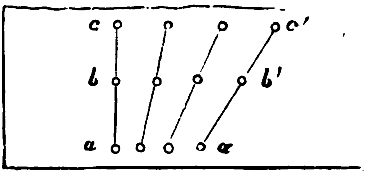


FIG. 18.

The most rapid motion (thirty-seven inches per day) observed by Professor Tyndall upon the Alpine glaciers occurred in midsummer. In winter the rate was only about one-half as great; but in the year 1875 the Norwegian geologist, Helland, reported a movement of twenty metres (about sixty-five feet) per day in the Jakobshavn Glacier which enters Disco Bay, Greenland, about latitude 70°. For some time there was a disposition on the part of many scientific men to doubt the correctness of Helland's calculations. Subsequent observations have shown, however, that from the comparatively insignificant glaciers of the Alps they were not justified in drawing inferences with respect to the motion of the vastly larger masses which come down to the sea through the fiords of Green-

land. The Jakobshavn Glacier was about two and a half miles in width and its depth very likely more than a thousand feet, making a cross-section of more than 1,400,000 square yards, whereas the cross-section of the Mer de Glace at Montanvert is estimated to be but 190,000 square yards or only about one-seventh the above estimate for the Greenland glacier. As the friction of the sides would be no greater upon a large stream than upon a small one, while upon the bottom it would be only in proportion to the area, it is evident that we cannot tell beforehand how rapidly an increase in the volume of the ice might augment the velocity of the glacier.

At any rate, all reasonable grounds for distrusting the accuracy of Helland's estimates seem to have been removed by later investigations. According to my own observations in the summer of 1886 upon the Muir Glacier, Alaska, the central portions, a mile back from the front of that vast ice-current, were moving from sixty-five to seventy feet per day. These observations were taken with a sextant upon pinnacles of ice recognizable from a base-line established upon the shore. It is fair to add, however, that during the summer of 1890 Professor H. F. Reid attempted to measure the motion of the same glacier by methods promising greater accuracy than could be obtained by mine. He endeavoured to plant, after the method of Tyndall, a line of stakes across the ice-current. But with his utmost efforts, working inwards from both sides, he was unable to accomplish his purpose, and so left unmeasured a quarter of a mile or more of the most rapidly-moving portion of the glacier. His results, therefore, of ten feet per day in the most rapidly-moving portion observed cannot discredit my own observations on a portion of the stream inaccessible by his method. A quarter of a mile in width near the centre of so vast a glacier gives ample opportunity for a much greater rate of motion than that observed by Professor Reid. Especially may this be

true in view of Tyndall's suggestion that the contour of the bottom over which the ice flows may greatly affect the rate in certain places. A sudden deepening of the channel may affect the motion of ice in a glacier as much as it does that of water in a river.

Other observations also amply sustain the conclusions of Helland. As already stated, the Danish surveying party under Steenstrup, after several years' work upon the south-western coast of Greenland, have ascertained that the numerous glaciers coming down to the sea in that region and furnishing the icebergs incessantly floating down Baffin's Bay, move at a rate of from thirty to fifty feet per day, while Lieutenants Ryder and Bloch, of the Danish Navy, who spent the year 1887 in exploring the coast in the vicinity of Upernavik, about latitude 73°, found that the great glacier entering the fiord east of the village had a velocity of ninety-nine feet per day during the month of August.*

It is easier to establish the fact of glacial motion than to explain how the motion takes place, for ice seems to be as brittle as glass. This, however, is true of it only when compelled suddenly to change its form. When subjected to slow and long-continued pressure it gradually yet readily yields, and takes on new forms. From this capacity of ice, it has come to be regarded by some as a really viscous substance, like tar or cooling lava, and upon that theory Professor Forbes endeavours to explain all glacial movement.

The theory, however, seems to be contradicted by familiar facts; for the iceman, after sawing a shallow groove across a piece of ice, can then split it as easily as he would a piece of sandstone or wood. On the glaciers themselves, likewise, the existence of innumerable crevasses would seem to contradict the plastic theory of glacier motion;

* Nature, December 29, 1887.

for, wherever the slope of the glacier's bed increases, crevasses are formed by the increased strain to which the ice is subjected. Crevasses are also formed in rapidly-moving glaciers by the slight strain occasioned by the more rapid motion of the middle portion. Still, in the words of Tyndall, "it is undoubted that the glacier moves like a viscous body. The centre flows past the sides, the top flows over the bottom, and the motion through a curved valley corresponds to fluid motion." *

To explain this combination of the seemingly contradictory qualities of brittleness and viscosity in ice, physicists have directed attention to the remarkable transformations which take place in water at the freezing-point. Faraday discovered in 1850 that "when two pieces of thawing ice are placed together they freeze together at the point of contact.†

"Place a number of fragments of ice in a basin of water and cause them to touch each other; they freeze together where they touch. You can form a chain of such fragments; and then, by taking hold of one end of the chain, you can draw the whole series after it. Chains of icebergs are sometimes formed in this way in the arctic seas." ‡

This is really what takes place when a hard snow-ball is made by pressure in the hand. So, by subjecting fragments of ice to pressure it is first crumbled to powder, and then, as the particles are pressed together in close contact, it resumes the nature of ice again, though in a different form, taking now the shape of the mould in which it has been pressed.

Thus it is supposed that, when the temperature of ice is near the melting-point, the pressure of the superincumbent mass may produce at certain points insensible disintegration, while, upon the removal of the pressure by

* Forms of Water, p. 163. † Ibid., p. 164. ‡ Ibid., pp. 164, 165.

change of position, regelation instantly takes place, and thus the phenomena which simulate plasticity are produced. As the freezing-point of water is, within a narrow range, determined by the amount of pressure to which it is subjected, it is not difficult to see how these changes may occur. Pressure slightly lowers the freezing-point, and so would liquefy the portions of ice subjected to greatest pressure, wherever that might be in the mass of the glacier, and thus permit a momentary movement of the particles, until they should recongeal in adjusting themselves to spaces of less pressure.* This is the theory by which Professor James Thompson would account for the apparent plasticity of glacial ice.

* Forms of Water, p. 168.

CHAPTER IV.

SIGNS OF PAST GLACIATION.

THE facts from which we draw the inference that vast areas of the earth's surface which are now free from glaciers were, at a comparatively recent time, covered with them, are fourfold, and are everywhere open to inspection. These facts are: 1. Scratches upon the rocks. 2. Extensive unstratified deposits of clay and sand intermingled with scratched stones and loose fragments of rock. 3. Transported boulders left in such positions and of such size as to preclude the sufficiency of water-carriage to account for them. 4. Extensive gravel terraces bordering the valleys which emerge from the glaciated areas. We will consider these in their order:

1. The scratches upon the rocks.

Almost anywhere in the region designated as having been covered with ice during the Glacial period, the surface of the rocks when freshly uncovered will be found to be peculiarly marked by grooves and scratches more or less fine, and such as could not be produced by the action of water. But, when we consider the nature of a glacier, these marks seem to be just what would be produced by the pushing or dragging along of boulders, pebbles, gravel, and particles of sand underneath a moving mass of ice.

Running water does indeed move gravel, pebbles, and boulders along with the current, but these objects are not held by it in a firm grasp, such as is required to make a groove or scratch in the rock. If, also, there are inequali-

ties in the compactness or hardness of the rock, the natural action of running water is to hollow out the soft parts, and leave the harder parts projecting. But, in the phenomena which we are attributing to glacial action, there has been a movement which has steadily planed

FIG. 19.—Bed-rock scored with glacial marks, near Amherst, Ohio. (From a photograph by Chamberlin.)

down the surface of the underlying rock; polishing it, indeed, but also grooving it and scratching it in a manner which could be accomplished only by firmly held graving-tools.

This polishing and scratching can indeed be produced

by various agencies; as, for example, by the forces which fracture the earth's crust, and shove one portion past another, producing what is called a *slicken-side*. Or, again, avalanches or land-slides might be competent to produce the results over limited and peculiarly situated areas. Icebergs, also, and shore ice which is moved backwards and forwards by the waves, would produce a certain amount of such grooving and scratching. But the phenomena to which we refer are so extensive, and occur in such a variety of situations, that the movement of glacial ice is alone sufficient to afford a satisfactory explanation. Moreover, in Alaska, Greenland, Norway, and Switzerland, and wherever else there are living glaciers, it is possible to follow up these grooved and striated surfaces till they disappear underneath the existing glaciers which are now producing the phenomena. Thus by its tracks we can, as it were, follow this monster to its lair with as great certainty as we could any animal with whose footprints we had become familiar.

2. The till, or boulder-clay.

A second sign of the former existence of glaciers over any area consists of an unstratified deposit of earthy material, of greater or less depth, in which scratched pebbles and fragments of rock occur without any definite arrangement.

Moving water is a most perfect sieve. During floods, a river shoves along over its bed gravel and pebbles of considerable size, whereas in time of low water the current may be so gentle as to transport nothing but fine sand, and the clay will be carried still farther onwards, to settle in the still water and form a delta about the river's mouth. The transporting capacity of running water is in inverse ratio to the sixth power of its velocity. Other things being equal, if the velocity be doubled, the size of the grains of sand or gravel which it transports is in-

creased sixty-four fold.* So frequent are the changes in the velocity of running water, that the stratification of its deposits is almost necessary and universal. If large

FIG. 20.—Scratched stone from the till of Boston. Natural size about one foot and a half long by ten inches wide. (From photograph.)

fragments of rocks or boulders are found embedded in stratified clay, it is pretty surely a sign that they have been carried to their position by floating ice. A small mountain stream with great velocity may move a good-sized boulder, while the Amazon, with its mighty but slow-moving current, would pass by it forever without

* Le Conte's Geology, p. 19.

stirring it from its position. But the vast area which is marked in our map as having been covered with ice during the Glacial period is characterised by deep and exten-

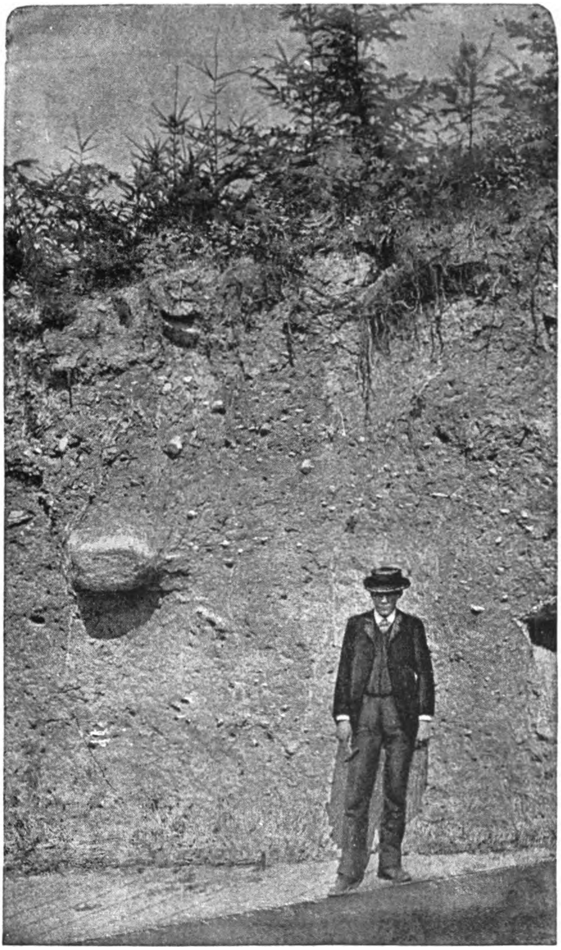


FIG. 21.—Typical section of till in Seattle, Washington State, about two hundred feet above Puget Sound. This is on the height between the sound and Lake Washington.

sive deposits of loose material devoid of stratification, and composed of soil and rock gathered in considerable part from other localities, and mixed in an indiscriminate mass with material which has originated in the disintegration of the underlying local strata.

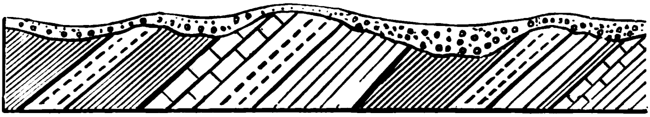


FIG. 22.—Ideal section, showing how the till overlies the stratified rocks.

3. Transported boulders.

Where there is a current of water deep enough to float large masses of ice, there is scarcely any limit to the size of boulders which may be transported upon them, or to

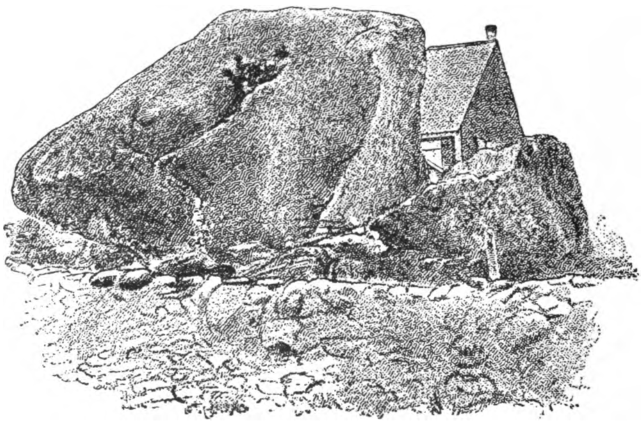


FIG. 23.—Vessel Rock, a glacial boulder in Gilsum, N. H. (C. H. Hitchcock.)

the distance to which the boulders may be carried and dropped upon the bottom. The icebergs which break off from the glaciers of Greenland may bear their burdens of rock far down into the Atlantic, depositing them finally amidst the calcareous ooze and the fine sediment from the

Gulf Stream which is slowly covering the area between Northern America and Europe. Northern streams like the St. Lawrence, which are deeply frozen over with ice in the winter, and are heavily flooded as the ice breaks up in the spring, afford opportunity for much transportation of boulders in the direction of their current. In attributing the transportation of a boulder to glacial ice, it is necessary, therefore, to examine the contour of the country, so as to eliminate from the problem the possibility of the effects having been produced by floating ice.

Another source of error against which one has to be on his guard arises from the close resemblance of boulders resulting from disintegration to those which have been transported by ice from distant places. Owing to the fact that large masses of rocks, especially those which are crystalline, are seldom homogeneous in their structure, it results that, under the slow action of disintegrating and erosive agencies, the softer parts often are completely removed before the harder nodules are sensibly affected, and these may remain as a collection of boulders dotting the surface. Such boulders are frequent in the granitic regions of North Carolina and vicinity, where there has been no glacial transportation. Several localities in Pennsylvania, also, south of the line of glacial action as delineated by Professor Lewis and myself, had previously been supposed to contain transported boulders of large size, but on examination they proved in all cases to be resting upon undisturbed strata of the parent rock, and were evidently the harder portions of the rock left *in loco* by the processes of erosion spoken of. In New England, also, it is possible that some boulders heretofore attributed to ice-action may be simply the results of these processes of disintegration and erosion. Whether they are or not can usually be determined by their likeness or unlikeness to the rocks on which they rest; but oftentimes, where a particular variety of rock is exposed over a broad area, it

is difficult to tell whether a boulder has suffered any extensive transportation or not.

One of the most interesting and satisfactory demonstrations of the distribution of boulders by glacial ice was furnished by Guyot in Switzerland in 1845. His observations and argument will be most readily understood by reference to the accompanying map, taken from Lyell's clear description.* The Jura Mountains are separated from the Alps by a valley, about eighty miles in width, which constitutes the main habitable portion of Switzerland, and they rise upwards of two thousand feet above it. But large Alpine boulders are found as high as two thousand feet above the Lake Neufchâtel upon the flanks of the Jura Mountains beyond Chasseron (at the point marked G on the map), and the whole valley is dotted with Alpine boulders. Upon comparing these with the native rocks in the Alps, Guyot in many cases was able to determine the exact centres from which they were distributed, and the distribution is such as to demonstrate that glacial ice was the medium of distribution.

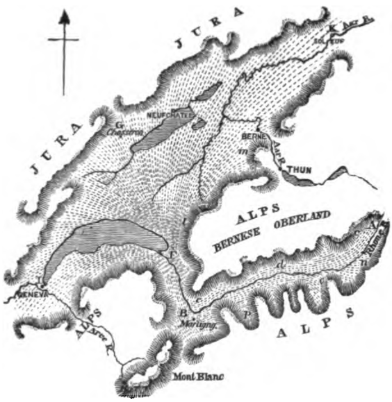


FIG. 24.—Map showing the outline and course of flow of the great Rhône Glacier (after Lyell).

For example, the dotted lines upon the map indicate the motion of the transporting medium. On ascending the valley of the Rhône to A, the diminutive representative of the ancient glacier is still found in existence, and

* Antiquity of Man, p. 299.

is at work transporting boulders and moraines according to the law of ice-movement. Following down the valley from A, boulders from the head of the Rhône Valley are found distributed as far as B at Martigny, where the valley turns at right angles towards the north. It is evident that floating ice in a stream of water would by its momentum be carried to the left bank, so that if icebergs were the medium of transportation we should expect to find the boulders from the right-hand side of the Rhône Valley distributed towards the left end of the great valley of Switzerland—that is, in the direction of Geneva. But, instead, the boulders derived from C, D, and E, on the Bernese Oberland side, instead of crossing the valley at B, continue to keep on the right-hand side and are distributed over the main valley in the direction of the river Aar.

As is to be expected also, the direct northward motion of the ice from B is stronger than the lateral movement to the right and left after it emerges from the mouth of the Rhône Valley, at F, and consequently it has pushed forwards in a straight line, so as to raise the Alpine boulders to a greater height upon the Jura Mountains at G than anywhere else, the upper limit of boulders at G being 1,500 feet higher than the limits at I or K on the left and right, points distant about one hundred miles from each other. All the boulders to the right of the line from B to G have been derived from the right side of the Rhône, while all the boulders to the left of that line have been derived from its left side.

A boulder of talcose granite containing 61,000 French cubic feet, measuring about forty feet in one direction, came, according to Charpentier, from the point *n*, near the head of the Rhône Valley, and must have travelled one hundred and fifty miles to reach its present position.

It scarcely needs to be added that the grooves and scratches upon the rocks over the floor of this great valley

of Switzerland indicate a direction of the ice-movement corresponding to that implied in the distribution of boulders. Thus, at K upon the map referred to, Lyell reports that the abundant grooves and striæ upon the polished marble all trend down the valley of the Aar.*

Similar facts concerning the transportation of boulders have been observed at Trogen, in Appenzel, where boulders derived from Trons, one hundred miles distant, are found to keep upon the left bank of the Rhine, however much the valley may wind about; and in some places, as at Mayenfeld, it turns almost at right angles, as did the Rhône at Martigny. Upon reaching the lower country at Lake Constance, these granite blocks from the left side of the valley deploy out upon the same side and do not cross over, as they would inevitably have done had they been borne along by currents of water.

In America we do not have quite so easy a field as is presented in Switzerland for the discovery of crucial instances showing that boulders have been transported by glacial ice rather than by floating ice, for in Switzerland the glaciated area is comparatively small and the diminutive remnants of former glaciers are still in existence, furnishing a comprehensive object-lesson of great interest and convincing power. Still, it is not difficult to find decisive instances of glacial transportation even in the broad fields of America which now retain no living remnants of the great continental ice-sheet.

As every one who resides in or who visits New England knows, boulders are scattered freely over all parts of that region, but for a long time the theory suggested to account for their distribution was that of floating ice during a period of submergence. One of the most convincing evidences that the boulders were distributed by glacial ice rather than by icebergs is found in Professor C. H. Hitch-

* Antiquity of Man, p. 305.

cock's discovery of boulders on the summit of Mount Washington (over 6,000 feet above the sea), which he was able to identify as derived from the ledges of light grey Bethlehem gneiss, whose nearest outcrop is in Jefferson, several miles to the northwest, and 3,000 or 4,000 feet lower than Mount Washington. However difficult it may be to explain the movement of these boulders by glacial ice, it is not impossible to do so, but the attempt to account for their transportation by floating ice is utterly preposterous. No iceberg could pick up boulders so far beneath the surface of the water, and even if it could advance thus far in its work it could not by any possibility land them afterwards upon the summit of Mount Washington.

Among the most impressive instances of boulders evidently transported by glacial ice, rather than by icebergs, were some which came to my notice when, in company with the late Professor H. Carvill Lewis, I was tracing the glacial boundary across the State of Pennsylvania. We had reached the elevated plateau (two thousand feet above the sea) which extends westwards and southwards from the peak of Pocono Mountain, in Monroe County. This plateau consists of level strata of sandstone, the southern part of which is characterised by a thin sandy soil, such as is naturally formed by the disintegration of the underlying rock, and there is no foreign material to be found in it. But, on going northwards to the boundary of Tobyhanna township, we at once struck a large line of accumulations, stretching from east to west, and rising to a height of seventy or eighty feet. This was chiefly an accumulation of transported boulders, resembling in its structure the terminal moraines which are found at the front of glaciers in the Alps and in Alaska, and indeed wherever active glaciers still remain. But here we were upon the summit of the mountain, where there are no higher levels to the north of us, down which the ice could flow. Be-

sides, among these boulders we readily recognised many of granite, which must have come either from the Adirondack Mountains, two hundred miles to the north, or from the Canadian highlands, still farther away.

Limiting our observations simply to the boulders, we should indeed have been at liberty to suppose that they had been transported across the valley of the Mohawk or of the Great Lakes by floating ice during a period of submergence. But we were forbidden to resort to this hypothesis by the abrupt marginal line, running east and west, upon Pocono plateau, along which these northern boulders ceased. South of this evident terminal moraine there was no barrier, and there were no northern boulders. On the theory of submergence, there was no reason for the boundary-line so clearly manifested. Ice which had floated so far would have floated farther.

Still further, on going a few miles east of the Pocono plateau, one descends into a parallel valley, lying between Pocono Mountain and Blue Mountain, and one thousand feet below their level. But our marginal southern boundary of transported granite rocks did not extend much farther south in the valley than it did on the plateau, except where we could trace the action of a running stream, evidently corresponding to the subglacial rivers which pour forth from the front of every extensive glacier. In these facts, therefore, we had a crucial test of the glacial hypothesis, and, in view of them, could maintain, against all objectors, the theory of the distant glacial transportation of boulders, even over vast areas of the North American continent.

Since that experience, I have traced this limit of southern boulders for thousands of miles across the continent, according to the delineation which may be seen in the map in a later chapter. If necessary, I could indicate hundreds of places where the proof of glacial transportation is almost as clear as that on the Pocono plateau

in Pennsylvania. One of the most interesting of these is on the hills in Kentucky, about twelve miles south of the Ohio River, at Cincinnati, where I discovered boulders of a conglomerate containing many pebbles of red jasper, which can be identified as from a limited formation crop-

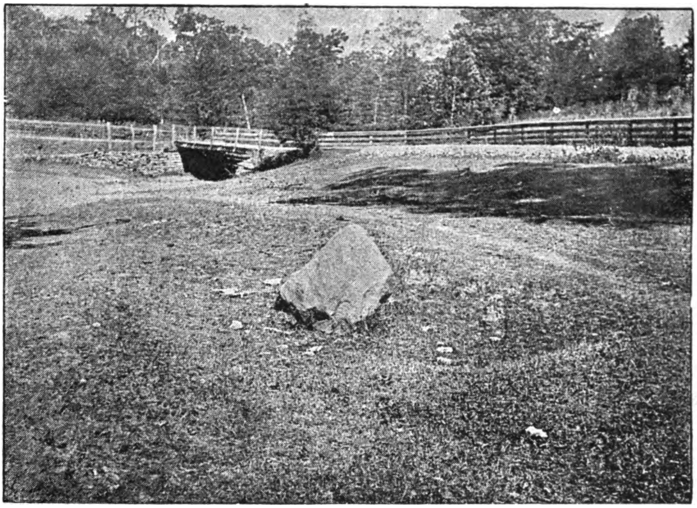


FIG. 25.—Conglomerate boulder found in Boone County, Kentucky. (See text.)

ping out in Canada, to the north of Lake Huron, six hundred or seven hundred miles distant. That this was transported by glacial ice, and not by floating ice, is evident from the fact that here, too, there was no barrier to the south, requiring deposits to cease at that point, and from the further fact that boulders of this material are found in increasing frequency all the way from Kentucky to the parent ledges in Canada. With reference to these boulders, as with reference to those found on the summit of Mount Washington, we can reason, also, that any northerly subsidence permitting a body of water to occupy the space between Kentucky and Lake Superior, and deep

enough to facilitate the movement across it of floating ice, would render it impossible for the ice to have loaded itself with them.

The same line of reasoning is conclusive respecting the innumerable boulders which cover the northern portion of Ohio, where I have my residence. The whole State of Ohio, and indeed almost the entire Mississippi basin between the Appalachian and the Rocky Mountains, is completely covered, and to a great depth, with stratified rocks which have been but slightly disturbed in the elevation of the continent; yet, down to an irregular border-line running east and west, granitic boulders everywhere occur in great numbers. In the locality spoken of in northern Ohio the elevation of the country is from two hundred to five hundred feet above the level of Lake Erie. The nearest outcrops of granitic rock occur about four hundred miles to the north, in Canada. After the meeting of the American Association for the Advancement of Science in Toronto in the summer of 1889, I had the privilege of joining a company of geologists in an excursion, conducted by members of the Canadian Survey, to visit the region beyond Lake Nipissing, north of Lake Huron, where the ancient Laurentian and Huronian rocks are most typically developed. I took advantage of the trip to collect specimens of a great variety of the granites and gneisses and metamorphic schists and trap-rock of the region. On bringing them home I turned them over to the professor of geology, who at once set his class at work to see if they could match my fragments from Canada with corresponding fragments from the boulders of the vicinity. To the great gratification, both of the pupils and myself, they were able to do so in almost every case; and so they might have done in any county or township to the south until reaching the limit of glacier action which I had previously mapped. Here, at Oberlin, on the north side of the watershed, it is possible to imagine that we are on the southern

border of an ancient lake upon whose bosom floating ice had brought these objects from their distant home in Canada. But this theory would not apply to the portion of the State which is south of the water-shed and which slopes rapidly towards the Gulf of Mexico. Yet the distribution of boulders is practically uniform over the glaciated area on both sides of the water-shed, constituting thus an indisputable proof of the glacial theory.

4th. As the significance of the gravel terraces which mark the lines of outward drainage from the glaciated area cannot well be indicated in a single paragraph, the reader is referred for further information upon this point to the general statements respecting them throughout the next chapter.

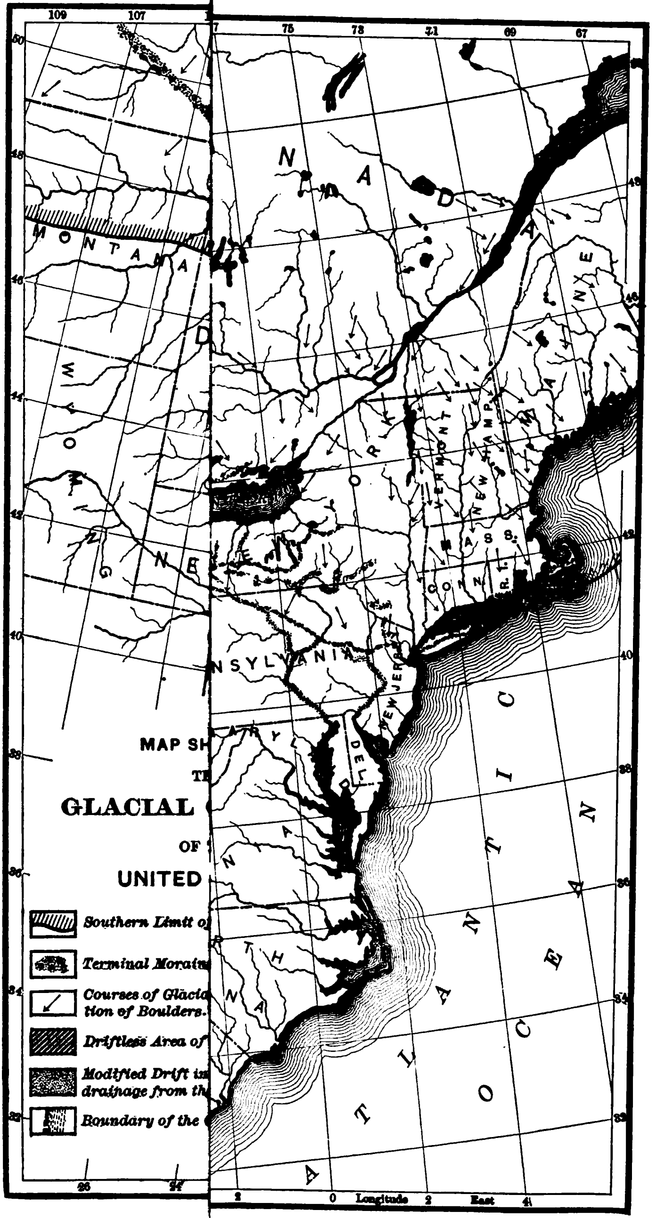
CHAPTER V.

ANCIENT GLACIERS IN THE WESTERN HEMISPHERE.

New England.

In North America all the indubitable signs of glacial action are found over the entire area of New England, the southern coast being bordered by a double line of terminal moraines. The outermost of these appears in Nantucket, Martha's Vineyard, No Man's Land, Block Island, and through the entire length of Long Island—from Montauk Point, through the centre of the island, to Brooklyn, N. Y., and thence across Staten Island to Perth Amboy in New Jersey. The interior line is nearly parallel with the outer, and, beginning at the east end of Cape Cod, runs in a westerly direction to Falmouth, and thence southwesterly through Wood's Holl, and the Elizabeth Islands—these being, indeed, but the unsubmerged portions of the moraine. On the mainland this interior line reappears near Point Judith, on the south shore of Rhode Island, and, running slightly south of west, serves to give character to the scenery at Watch Hill, and thence crops out in the Sound as Fisher and Plum Islands, and farther west forms the northern shore of Long Island to Port Jefferson.

In these accumulations bordering the southern shore of New England, the characteristic marks of glacial action can readily be detected even by the casual observer, and prolonged examination will amply confirm the first impression. The material of which they are composed is,



MAP SH
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GLACIAL
OF
UNITED
Southern Limit of
Terminal Moraine
Courses of Glacia
tion of Boulders.
Driftless Area of
Modified Drift in
drainage from th
Boundary of the
MONTANA
WYOMING
NEBRASKA
DAKOTA
CANADA
NEW YORK
PENNSYLVANIA
NEW JERSEY
MARYLAND
DEL.
VERMONT
NEW HAMP.
MASS.
CONN.
R.I.
MAINE
NORTH CAROLINA
ATLANTIC OCEAN
Longitude East

for the most part, foreign to the localities, and can be traced to outcrops of rock at the north. The boulders scattered over the surface of Long Island, for example, consist largely of granite, gneiss, hornblende, mica slate, and red sandstone, which are easily recognised as fragments from well-known quarries in Connecticut, Rhode Island, and Massachusetts; yet they have been transported bodily across Long Island Sound, and deposited in a heterogeneous mass through the entire length of the island. Not only do they lie upon the surface, but, in digging into the lines of hills which constitute the backbone of Long Island, these transported boulders are found often to make up a large part of the accumulation. Almost any of the railroad excavations in the city of Brooklyn present an interesting object-lesson respecting the composition of a terminal moraine.

All these things are true also of the lines of moraine farther east, as just described. Professor Shaler has traced to its source a belt of boulders occurring extensively over southern Rhode Island, and found that they have spread out pretty evenly over a triangular area to the southward, in accordance with the natural course to be pursued by an ice-movement. Nearly all of Plymouth County, in southeastern Massachusetts, is composed of foreign material, much of which can be traced to the hills and mountains to the north. Even Plymouth Rock is a boulder from the direction of Boston, and the "rock-bound" shores upon which the Pilgrims are poetically conceived to have landed are known, in scientific prose, as piles of glacial rubbish dumped into the edge of the sea by the great continental ice-sheet.

The whole area of southeastern Massachusetts is dotted with conical knolls of sand, gravel, and boulders, separated by circular masses of peat or ponds of water, whose origin and arrangement can be accounted for only by the peculiar agency of a decaying ice-front. Indeed, this

whole line of moraines, from the end of Cape Cod to Brooklyn, N. Y., consists of a reticulated network of ridges and knolls, so deposited by the ice as to form innumerable kettle-holes which are filled with water where other conditions are favourable. Those which are dry are so because of their elevation above the general level, and of the looseness of the surrounding soil; while many have been filled with a growth of peat, so that their original character as lakelets is disguised.

As already described, these depressions, so characteristic of the glaciated region, are, in the majority of cases, supposed to have originated by the deposition of a great quantity of earthy material around and upon the masses of ice belonging to the receding front of the glacier, so that, when at length the ice melted away, a permanent depression in the soil was left, without any outlet.

To some extent, however, the kettle-holes may have been formed by the irregular deposition of streams of water whose courses have crossed each other, or where eddies of considerable force have been produced in any way. The ordinary formation of kettle-holes can be observed in progress on the foot of almost any glacier, or, indeed, on a small scale, during the melting away of almost any winter's snow. Where, from any cause, a stratum of dirt has accumulated upon a mass of compact snow or ice, it will be found to settle down in an irregular manner; furrows will be formed in various directions by currents of water, so that the melting will proceed irregularly, and produce upon a miniature scale exactly what I have seen on a large scale over whole square miles of the decaying foot of the great Muir Glacier in Alaska. The effects of similar causes and conditions we can see on a most enormous scale in the ten thousand lakes and ponds and peat-bogs of the whole glaciated area both in North America and in Europe.

In addition to these two lines of evidence of glacial action in New England, we should mention also the in-

numerable glacial grooves and scratches upon the rocks which can be found on almost any freshly uncovered surface. In New England the direction of these grooves is ordinarily a little east of south. Upon the east coast of Massachusetts and New Hampshire the scratches trend much more to the east than they do over most of the interior. This is as it should be on the glacial theory, since the ice would naturally move outwards in the line of least resistance, which would, of course, be towards the open sea wherever that is near. In the interior of New England the scratches upon the rocks indicate a more southerly movement in the Connecticut Valley than upon the mountains in the western part of Massachusetts. This also is as it should be upon the glacial theory. The scratches upon the mountains were made when the ice was at its greatest depth and when it moved over the country in comparative disregard of minor irregularities of surface, while in the valleys, at least in the later portion of the Ice age, the movement would be obstructed except in one direction. In the interpretation of the glacial grooves and scratches it should always be borne in mind that they represent the work done during the closing stages of the period. Just as the last shove of the carpenter's plane removes the marks of the previous work, so the last rasping of a glacial movement wears away the surfaces which have been previously polished and striated.

In various places of New England it is interesting as well as instructive to trace the direction of the ice-movement by the distribution of boulders. My own attention was early attracted to numerous fragments of gneiss in eastern Massachusetts containing beautiful crystals of porphyry, which proved to be peculiar to the region of Lake Winnepesaukee, a hundred miles to the north, and to a narrow belt stretching thence to the southwestward. In ascending almost any of the lower summits of the

White Mountains one's attention can scarcely fail of being directed to the difference between the material of which the mountains are composed and that of the numerous boulders which lie scattered over the surface. The local geologist readily recognises these boulders as pilgrims that have wandered far from their homes to the northward.

Trains of boulders, such as those already described in Rhode Island, can frequently be traced to some prominent outcrop of the rock in a hill or mountain-peak from which they have been derived. One of the earliest of these to attract attention occurs in the towns of Richmond, Lenox, and Stockbridge, in the western part of Massachusetts. Here a belt of peculiar boulders about four hundred feet wide is found to originate in the town of Lebanon, N. Y., and to run continuously to the southeast for a distance of nine miles. West of Fry's Hill, where the outcrop occurs, no boulders of this variety of rock are to be found, while to the southeast the boulders gradually diminish in size as their distance from the outcrop increases. Near the outcrop boulders of thirty feet in diameter occur, while nine miles away two feet is the largest diameter observed.

Sir Charles Lyell endeavoured to explain this train of boulders by the action of icebergs during a period of submergence—supposing that, as icebergs floated past or away from this hill in Lebanon, N. Y., they were the means of the regular distribution described. It is needless to repeat the difficulties arising in connection with such a theory, since now both by observation and experiment we have become more familiar with the movement of glacial ice. What we have already said about the transportation of boulders over Switzerland by the Alpine glaciers, and what is open to observation at the present time upon the large glaciers of Alaska, closely agree with the facts concerning this Richmond train of boulders, and we have no occasion to look further for a cause.

Indeed, trains of boulders ought to appear almost everywhere over the glaciated area; and so they do where all the circumstances are favourable. But, readily to identify the train, requires that to furnish the boulders there should be in the line of the ice-movement a projecting mass of rock hard enough to offer considerable resistance to the abrading agency of the ice and characteristic enough in its composition to be readily recognised. Ship Rock, in Peabody, Mass., weighing about eleven hundred tons, and Mohegan Rock, in Montville, Conn., weighing about ten thousand tons, have ordinarily been pointed to as boulders illustrating the power of ice-action. Their glacial character, however, has been challenged from the fact that the variety of granite to which they belong occurs in the neighbourhood, and indeed constitutes the bed-rock upon which they rest.* Some would therefore consider them. like some of which we have already spoken, to be boulders which have originated through the disintegration of great masses of rock, of which these were harder nuclei that have longer resisted the ravages of the tooth of time. It must be admitted that possibly this explanation is correct; but it is scarcely probable that, in a region where there are so many other evidences of glacial action, these boulders could have remained immovable in presence of the onward progress of the ice-current that certainly passed over them.

However, as already seen, we are not left to doubt as to the movement of some boulders of great size. That which now claims the reputation of being the largest in New England is in Madison, N. H., and measures thirty by forty by seventy-five feet. This can be traced to ledges of Conway granite, about two miles away.† Many boulders in the vicinity of New Haven, Conn., can be

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* Popular Science Monthly, vol. xxxvii, pp. 196–201.

† See W. O. Crosby's paper in Appalachia, vol. vi, pp. 59–70.

identified, as from well-known trap-dykes, sixteen miles or more to the north. The so-called Judge's Cave, on West Rock, 365 feet above the adjoining valley and weighing a thousand tons, is one of these. Professor Ed-

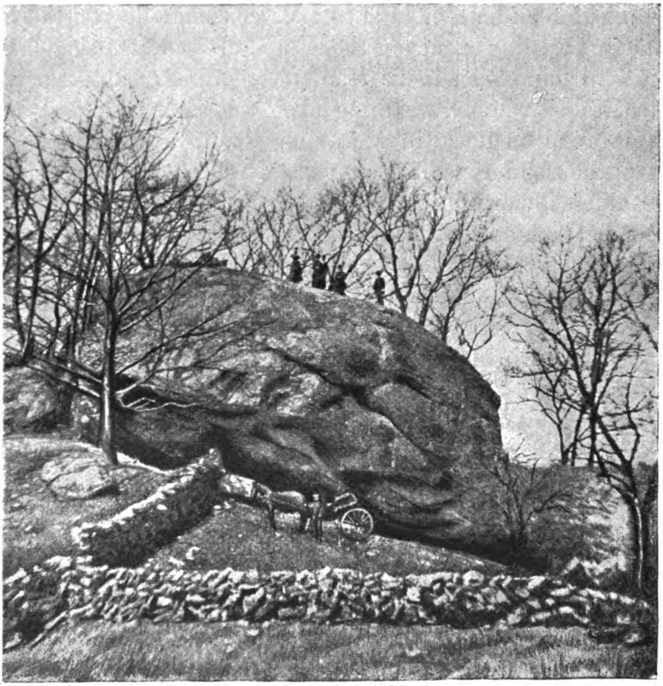

FIG. 26.—Mohegan Rock.

ward Orton * describes a mass of Clinton limestone near Freeport, Warren County, Ohio, as covering an area of three-fourths of an acre, and as sixteen feet in thickness. It overlies glacial clays and gravels, and must have been transported bodily from the elevations containing this rock several miles to the northwest.

* Geological Survey of Ohio, vol. iii, p. 385.

Portions of New England present the best illustrations anywhere afforded in America of what are called "drumlins." These are "lenticular-shaped" hills, composed of till, and containing, interspersed through their mass, numerous scratched stones of all sizes. They vary in length from a few hundred feet to a mile, and are usually from half to two-thirds as wide as they are long. In height they vary from twenty-five to two hundred feet.

But, according to the description of Mr. Upham, whatever may be their size and height, they are singularly alike in outline and form, usually having steep sides, with gently sloping, rounded tops, and presenting a very smooth and regular contour. From this resemblance in shape to an elliptical convex lens, Professor Hitchcock has called them *lenticular hills* to distinguish these deposits of till from the broadly flattened or undulating sheets which are common throughout New England.

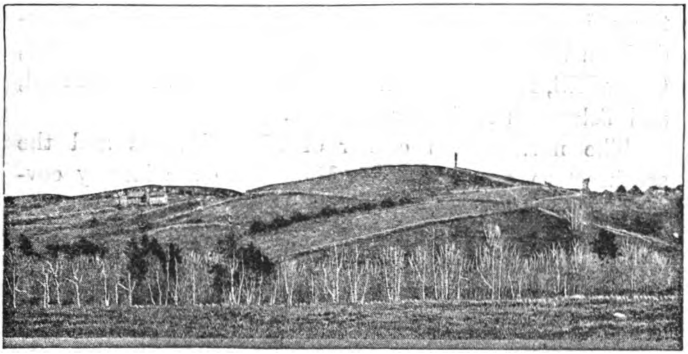

FIG. 27.—Drumlins in Goffstown, N. H. (Hitchcock).

The trend, or direction of the longer axis, of these lenticular hills is nearly the same for all of them comprised within any limited area, and is approximately like the course of the striæ or glacial furrows marked upon the neighbouring ledges. In eastern Massachusetts and

New Hampshire, within twenty-five miles of the coast, it is quite uniformly to the southeast, or east-southeast. Farther inland, in both of these States, it is generally from north to south, or a few degrees east of south; while in the valley of the Connecticut River it is frequently a little to the west of south. In New Hampshire, besides its accumulation in these hills, the till is frequently amassed in slopes of similar lenticular form. These have their position almost invariably upon either the south or north side of the ledgy hills against which they rest, showing a considerable deflection towards the southeast and northwest in the east part of the State. It cannot be doubted that the trend of the lenticular hills, and the direction taken by these slopes, have been determined by the glacial current, which produced the striæ with which they are parallel.*

Drumlins are abundant in the vicinity of Boston, and constitute nearly all the islands in Boston Harbour. On the mainland, Beacon Hill, Bunker Hill, Green Hill, Powderhorn Hill, Tufts College Hill, Winter Hill, Mount Ida, Corey Hill, Parker Hill, Wollaston Heights, Prospect Hill, and Telegraph Hill are specimens.

The northeastern corner of Massachusetts and the southeastern corner of New Hampshire are largely covered with these peculiar-shaped glacial deposits, while they are numerous as far west as Fitchburg, in Massachusetts, and Ware, N. H., and in the northeastern part of Connecticut. A little later, also, we shall refer to an interesting line of them in central New York. Elsewhere in America, except in a portion of Wisconsin, they rarely occur in such fine development as in New England. In Europe they are best developed in portions of Ireland.

One's first impression in examining an exposed section

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* Proceedings of the Boston Society of Natural History, vol. xx, pp. 224, 225.

of a drumlin would lead him to think that the mass was entirely unstratified; but closer examination shows that

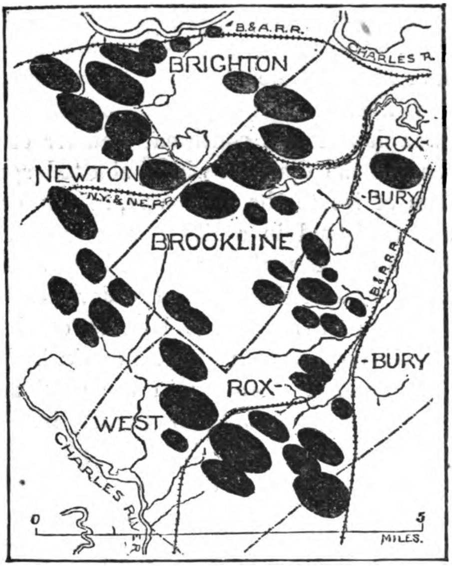

FIG. 28.—Drumlins in the vicinity of Boston (Davis).

there is a coarse stratification, but evidently not produced by water-action. The accumulation has probably taken place gradually by successive deposits underneath the glacier itself. Professor William M. Davis has suggested a plausible explanation which we will briefly state.

The frequency with which drumlins are found to rest upon a mass of projecting rock, the general co-ordination of the direction of their axes with the direction of the scratches upon the underlying rock, and the abundance of scratched stones in them, all support the theory that drumlins are formed underneath the ice-sheet, somewhat in the way that islands and bars of silt are formed in the delta of a great river. The movement of ice seems to

have been concentrated in pretty definite lines, often determined by the contour of the bottom, leaving a slacker movement in intervening areas, which were evidently protected in some cases by projecting masses of rock. In these areas of slower movement there was naturally an accumulation at the same time that there was vigorous erosion in the lines of more rapid movement.

There was doubtless a continual transfer of material from the end of the drumlin which abutted against the moving mass of ice to the lower end, as there is in the formation of an island in a river. If time enough had elapsed, the whole accumulation would have been levelled by the glacier and spread over the broader area where the more rapid lines of movement became confluent, and where the differential motion was less marked. Drumlins are thus characteristic of areas in the glaciated region whose floor was originally only moderately irregular, and where there was an excessive amount of ground moraine to be transported, and where the movement did not continue indefinitely. It has been suggested, also, that some of the long belts of territory in New England and central New York covered by drumlins may represent old terminal moraines which were subsequently surmounted by a re-advance of the ice, and partially wrought over into their present shape.

It is in New England, also, that kames are to be found in better development than anywhere else in America. These interesting remnants of the Glacial age are clearly described by Mr. James Geikie. His account will serve as well for New England as for Scotland.

The sands and gravels have a tendency to shape themselves into mounds and winding ridges, which give a hummocky and rapidly undulating outline to the ground. Indeed, so characteristic is this appearance, that by it alone we are often able to mark out the boundaries of the deposits with as much precision as we could were all the

vegetation and soil stripped away and the various subsoils laid bare. Occasionally, ridges may be tracked continuously for several miles, running like great artificial ramparts across the country. These vary in breadth and

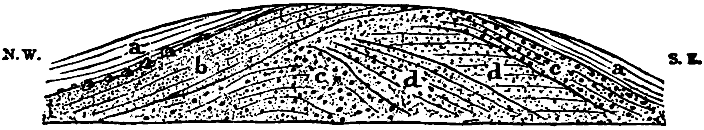

Fig. 29.—Section of kame near Dover, New Hampshire. Length, three hundred feet; height, forty feet; base, about forty feet above the Cocheco River, or seventy-five feet above the sea. *a, a,* gray clay; *b,* fine sand; *c, c,* coarse gravel containing pebbles from six inches to one foot and a half in diameter; *d, d,* fine gravel (Upham).

height, some of the more conspicuous ones being upward of four or five hundred feet broad at the base, and sloping upward at an angle of twenty-five or even thirty-five degrees, to a height of sixty feet and more above the general surface of the ground. It is most common, however, to find mounds and ridges confusedly intermingled, crossing and recrossing each other at all angles, so as to enclose deep hollows and pits between. Seen from some dominant point, such an assemblage of kames, as they are called, looks like a tumbled sea—the ground now swelling into long undulations, now rising suddenly into beautiful peaks and cones, and anon curving up in sharp ridges that often wheel suddenly round so as to enclose a lakelet of bright clear water.*

In New England attention was first directed to kames in 1842, by President Edward Hitchcock, in a paper before the American Association of Geologists and Naturalists, describing the gravel ridges in Andover, Mass. In the accompanying plate is shown a portion of this kame system, which has a double interest to me from the fact that it was while living upon the banks of the Shawshin

* The Great Ice Age, pp. 210, 211.

River, near where the kames and the river intersect, that I began, in 1874, my special study of glacial deposits. The

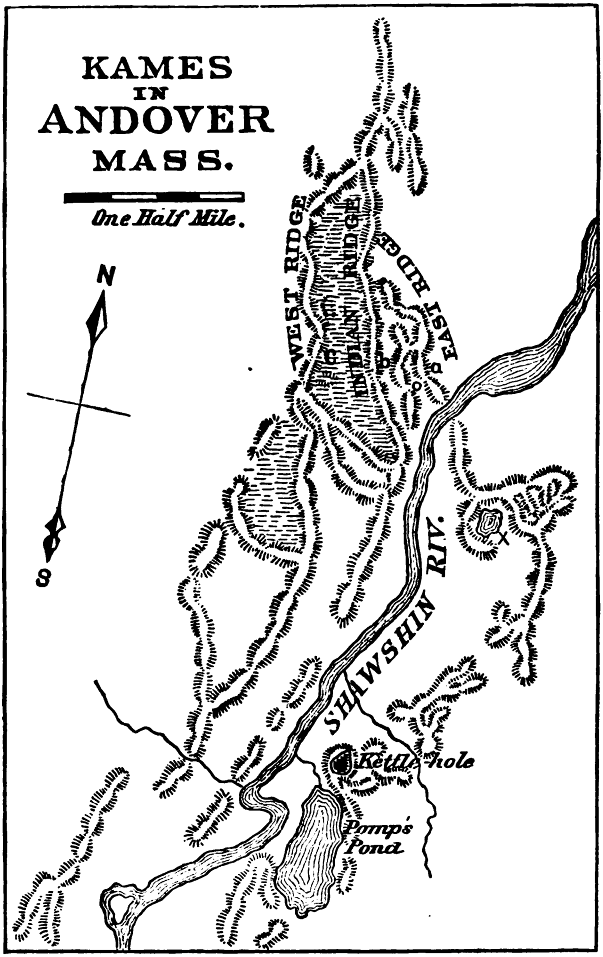

Fig. 30.

Andover ridges are composed of imperfectly stratified water-worn material, and are very sharply defined, from

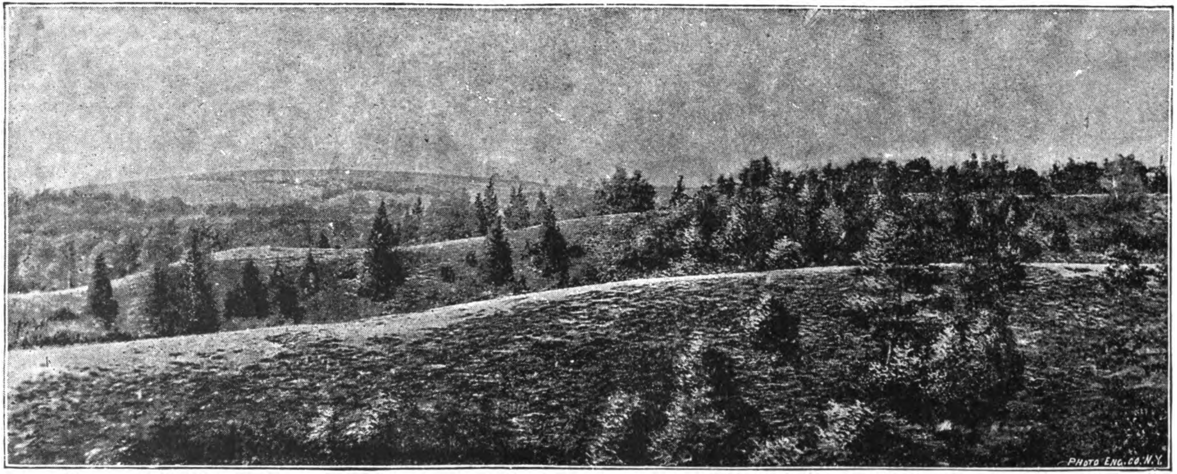

FIG. 31.—Longitudinal kames near Hingham, Massachusetts. The parallel ridges of gravel in the foreground run nearly east and west, and coalesce at each end, near the edges of the picture, to form an elongated kettle-hole. The ridges from fifty to sixty feet in height. The kame-stream was here evidently emptying into the ocean a few miles to the east (Bouvé).

the town of Chelsea, back from the coast into New Hampshire, for a distance of twenty-five miles. The base of the ridges does not maintain a uniform level, but the system descends into shallow valleys, and rises over elevations of one hundred to two hundred feet, without interruption. This indifference to slight changes of level is specially noticeable where the system crosses the Merrimac River, just above the city of Lawrence. It is also represented in the accompanying plate, where the base of the ridges in the immediate valley of the Shawshin is fifty feet lower than the base of those a short distance to the north, at the points marked *a*, *b*, and *c*. The ridges here terminate at the surface in a sharp angle, and are above their base forty-one feet at *a*, forty-nine feet at *b*, and ninety-one feet at *c*. Between *c* and *b* there is an extensive peat-swamp, filling the depression up to the level of an outlet through which the surplus water has found a passage.

Several systems of kames approximately parallel to this have been traced out in Massachusetts and New Hampshire, while the remnants of a very extensive system are found in the Connecticut Valley above the Massachusetts line. But they abound in greatest profusion in the State of Maine, where Professor George H. Stone has plotted them with much care. The accompanying map gives only an imperfect representation of the ramifying systems which he has traced out, and of the extent to which they are independent of the present river-channels. One of the longest of these extends more than one hundred miles, crossing the Penobscot River nearly opposite Grand Lake, and terminating in an extensive delta of gravel and sand in Cherryfield, nearly north of Mount Desert. This is represented on our map by the shaded portion west of the Machias River. Locally these ridges are variously designated as "horsebacks," "hogbacks," or "whalebacks," but that in Andover, Mass., was for some reason called "Indian Ridge." Nowhere else in the world

are these ridges better developed than in New England, except it be in southern Sweden, where they have long been known and carefully mapped.

FIG. 32.—The kames of Maine and southeastern New Hampshire. (Stone.)

The investigations of Mr. W. O. Crosby upon the composition of till in eastern Massachusetts is sufficiently im-

portant in its bearings upon the question of glacial erosion to merit notice at this point.* The object of his investigations was to determine how much of the so-called ground moraine, or till, consisted of material disintegrated by mechanical action, and how much by chemical action. The "residuary clay," which has arisen from chemical decomposition, would properly be attributed to the disintegrating agencies of preglacial times, while the clay, which is strictly mechanical in its origin, remains to represent the true "grist" or "rock flour" of the Glacial period.

The results of Mr. Crosby's investigations show that "not more than one-third of the *detritus* composing the till of the Boston Basin was in existence before the Ice age, and that the remaining two-thirds must be attributed to the mechanical action of the ice-sheet and its accompanying torrents of water. In other words, if we assume the average thickness of the drift as thirty feet, the amount of glacial erosion can scarcely fall below twenty feet. After scraping away the residuary clays and half-decomposed material, the ice-sheet has cut more than an equal depth into the solid rocks."

Mr. Crosby's investigations also convinced him that the movement of the till, or ground moraine, underneath the ice was not *en masse*, but that "it must have experienced differential horizontal movements or flowing, in which, normally, every particle or fragment slipped or was squeezed forward with reference to those immediately below it, the velocity diminishing downward through the friction of the underlying ledges. . . . The glaciation was not limited to masses which were firmly caught between the ice and the solid ledges, and it was in every case essentially a slipping and not a rolling movement. . . . These differential horizontal movements mean that the till acted as a lubri-

* Proceedings of the Boston Society of Natural History, vol. xxv (1890), pp. 115–140.

cant for the ice-sheet; and the clayey element, especially, co-operating in many cases with the pent-up subglacial waters, must have greatly facilitated the onward progress of the ice." He concludes, therefore, that the onward movement of the vast ice-sheet greatly exceeded that of the main part of the ground moraine, the ice-sheet slipping over the till, the whole being in some degree analogous to that of a great land-slip. "In both cases the progress of a somewhat yielding and mobile mass is facilitated by an underlying clayey layer saturated with water."

New York, New Jersey, and Pennsylvania.

West of New England the glacial phenomena over the northern part of the United States are equally marked all the way to the Missouri River, and the boundary-line of the glaciated region can be traced with little difficulty. It emerges from New York Bay on Staten Island and enters New Jersey at Perth Amboy. A well-formed moraine covers the northern part of Staten Island, and upon the mainland marks the boundary from Perth Amboy, around through Raritan, Plainfield, Chatham, Morris, and Hanover, to Rockaway, and thence in a southwesterly direction to Belvidere, on the Delaware River. That portion of New Jersey lying north of this serpentine line of moraine hills is characterised by the presence of transported boulders, by numerous lakes of evident glacial origin, and by every other sign of glacial action, while south of it all these peculiar characteristics are absent. The observant passenger upon the railroad trains between New York and Philadelphia can easily recognise the moraine as it is passed through on the Pennsylvania Railroad at Metuchen and on the Bound Brook Railroad at Plainfield. Near Drakestown, in Morris County, there is a mass of blue limestone measuring, as exposed, thirty-six by thirty feet, and which was quarried for years before discovering that it was a boulder

brought with other drift material from many miles to the northwest and lodged here a thousand feet above the sea.

Across Pennsylvania the glacial boundary passes through Northampton, Monroe, Luzerne, Columbia, Sullivan, Lycoming, Tioga, and Potter Counties, where it enters the State of New York, running still in a northwest direction through Allegany and Cattaraugus Counties to the vicinity of Salamanca. Here it turns to the south nearly at a right angle, running southwestward to Chautauqua County and re-entering Pennsylvania in Warren County, and thence passing onward in the same general direction through Crawford, Venango, Mercer, Butler, and Lawrence Counties to the Ohio line in Columbiana County, about ten miles north of the Ohio River.

The occurrence of a well-defined terminal moraine to mark the glacial boundary eastward from Pennsylvania led Professor Lewis and myself, who made the survey of that State in 1880, to be rather too sanguine in our expectations of finding an equally well-marked moraine everywhere along the southern margin of the glaciated area; still, the results are even more interesting than would have been the exact fulfilment of our expectations, since they more fully revealed to us the great complexity of effect which is capable of being brought about by ice-action. Before proceeding farther with the details, therefore, it will be profitable at this point to pause in the narrative and briefly record a few generalisations that have forced themselves into prominence during the years in which field-work has been in progress.

Previous to our explorations in Pennsylvania it had been thought that the indications of ice-action would extend much farther south in the valleys than on the mountains, and this indeed would have been the case if the glaciers in northern Pennsylvania had been of local origin; but our experience very soon demonstrated that the great gathering-place of the snows which produced

the glacial movement in northern Pennsylvania could not have been local, but that over the northern part of that State there was distinct evidence of a continental movement of ice whose centre was far beyond the Alleghanies.

For example, we found that the evidences of direct glacial action extended farther south upon the hills and higher plateaus than they did in the valleys, while everywhere on the very southern border of glacial indications we found boulders that had been brought from the granitic region of northern New York or central Canada. In eastern Pennsylvania we found indeed a terminal moraine more or less distinctly marking the southern border over the highlands. This was more specially true in Northampton and Monroe Counties.

In Northampton County it was very interesting to see long lines of hills, a hundred or more feet in height and lying several hundred feet above the Delaware River, composed entirely of glacial *débris*, much of which had been brought bodily over the sharp summit of the Blue Ridge, or Kittatinny Mountain, which rises as a continuous wall to the northwest and is everywhere several hundred feet higher than the moraine in Northampton County. The summit of Blue Ridge, also, as far south as the glacial movement extended, shows evident signs of glacial abrasion, some hundreds of feet evidently having been removed by that means, leaving a well-defined shoulder, marking the limits of its southwestern border. Resting upon the summit of the glaciated portion of the Blue Ridge, there are also numerous boulders of Helderberg limestone, which must have been brought from ledges at least five hundred feet lower than the places upon which they now lie.

In Monroe County the terminal moraine marking there the extreme limit of the ice-movement is upon an extensive plateau of Pocono sandstone, about eighteen hundred feet above sea-level, and five or six hundred feet lower than

the crest of the Alleghany Mountains, a short distance to the north. The moraine hills are here well marked by the occurrence of circular lakelets and kettle-holes (such as have been described as characteristic of the shores and islands bordering the south of New England); by the occurrence of granitic boulders, which must have been brought from the Adirondacks or Canada; and by the various other indications referred to on a previous page.

As already intimated, the instructive point in our observations is the fact that, between Kittatinny Mountain, in Northampton County, and Pocono plateau, in Monroe County, there is a longitudinal depression, running northeast by southwest, parallel with the ranges of the mountain system, which is here about a thousand feet below the respective ridges on either side. This, therefore, is one of the places where we should have expected a considerable southern extension of the ice, if it had been largely due to local causes. Now, while there is indeed a gradual southern trend down the flanks of the mountain, yet, upon reaching the axis of the valley, there appears at once a very marked change in the character of the deposit, and the influence of powerful streams of water becomes manifest, and it is evident, upon a slight inspection, that we have come upon a line of drainage which sustained a peculiar relation to the continental ice-sheet.

From Stroudsburg, near the Delaware Water-Gap, to Weissport, on the Lehigh River, a distance of about thirty miles, the valley between the mountains is continuous, and the elevation at each end very nearly the same. But about half-way between the two places, near Saylorsburg, there is a river-parting from which the water now runs on the one hand north to Stroudsburg, and thence to the Delaware River, and on the other hand south, through Big and Aquonchichola Creeks, to the Lehigh River. The river-parting is formed by a great accumulation of gravel, whose summit is about two hundred feet above the level of the

valleys into which the creeks empty at either end; and there are numerous kettle-holes and lakelets in the vicinity, such as characterize the glacial region in general.

In short, we are, without doubt, here on a well-marked terminal moraine much modified by strong water-action in a valley of glacial drainage. The gravel and boulders are all well water-worn, and the material is of various kinds, including granite boulders from the far north, such as characterise the terminal moraine on the highlands; but the pebbles are not scratched, and the gravel is more or less stratified. It is evident that we are here where a violent stream of water poured forth from that portion of the ice-front which filled this valley, and which found its only outlet in the direction of the Lehigh River. The gravel can be traced in diminishing quantities to the southward, in accordance with this theory, while to the northward there extends a series of gravel ridges, or kames, such as we have shown naturally to owe their origin to the accumulations taking place in ice-channels formed near the front of a glacier as it slowly melts away. *

From similar occurrences of vast gravel accumulations in other valleys stretching southward from the glacial margin, we came to expect that, wherever there was an open line of drainage from the glaciated region southward, the point of intersection between the glacial margin and the drainage valley would be marked by an excessive accumulation of water-worn gravel, diminishing in coarseness and abundance down the valleys in proportion to the distance from the glacial margin.

For example, the Delaware River emerges from the glaciated region at Belvidere, and there are there vast accumulations of gravel rising a hundred or more feet above the present level of the river, while gravel terraces, diminishing in height, mark the river below to tide-water at Trenton. The Lehigh River leaves the glaciated region at Hickory Run, a few miles above Mauch Chunk, but

*See Ed. H. Williams – Glaciation in Pennsylvania. [illegible] XX [illegible]

the gorge is so steep that there was little opportunity either for the accumulation of gravel there or for its preservation. Still, the transported gravel and boulders characteristic of the melting floods pouring forth from a glacier, are found lining the banks of the Lehigh all along the lower portion of its course. In the Susquehanna River we have a better example at Beach Haven, in Luzerne County, where there are very extensive accumulations of gravel resting on the true glacial deposits of the valley, and extending down the river in terraces of regularly diminishing height for many miles, and merging into terraces of moderate elevation which line the Susquehanna Valley throughout the rest of its course. Above Beach Haven the gravel deposits in the trough of the river valley are more irregular, and betray the modifying influence of the slowly decaying masses of ice which belonged to the enveloping continental glacier.

Westward from the north fork of the Susquehanna, similar extensive accumulations of gravel occur at the intersection of Fishing Creek in Columbia County, Muncy, Loyalsock, Lycoming, and Pine Creeks in Lycoming County, all tributary to the Susquehanna River, and all evidently being channels through which the melting floods of the ice-sheet brought vast quantities of gravel down to the main stream. Williamsport, on the West Branch of the Susquehanna, is built upon an extensive terrace containing much granitic material, brought down from the glaciated region by Lycoming Creek, when it was flooded with the waters melted from the continental ice-sheet which had here surmounted the Alleghanies and invaded the valley of the Susquehanna.

Analogous deposits of unusual amounts of gravel, occurring in streams flowing southward from the glaciated region, occur at Great Valley, Little Valley, and Steamburg in Cattaraugus County, New York, and at Russelburg and Garland in Warren County, Pennsylvania, also

at Titusville and Franklin in Venango County, and at Wampum in Lawrence County, of the same State.

As a rule, Professor Lewis and myself found it more difficult to determine with accuracy the exact point to which the ice extended in the axis of these south-flowing valleys than we did upon the highlands upon either side; and, in looking for the positive indications of direct ice-action in these lines of drainage, we were almost always led up the valley to a considerable distance inside of the line. This arose from our inexperience in interpreting the phenomena, or rather from our inattention to the well-known determining facts in the problem. On further reflection it readily appeared that this was as it should be. The ice-front, instead of extending farther down in a narrow valley than on the adjoining highlands (where they are of only moderate elevation) ought not to extend so far, for the subglacial streams would not only wear away the ice of themselves, but would admit the air into the tunnels formed by them so as to melt the masses both from below and from above, and thus cause a recession of the front. If we had understood this principle at the beginning of our survey, it would have saved us much perplexity and trouble.

A single further illustration of this point will help to an understanding of many references which will hereafter be made to the water deposits which accumulated in the lines of drainage running southward from the glaciated area. At Warren, Pa., Conewango Creek, which is the outlet from Chautauqua Lake, enters the Alleghany River after flowing for a number of miles in a deep valley with moderate slopes. In ascending the creek from Warren, the gravel terraces, which rise twenty-five or thirty feet above high-water mark, rapidly increase in breadth and height, and the pebbles become more and more coarse. After a certain distance the regular terraces begin to give place to irregular accumulations of gravel in ridges and

knobs. In the lower portion of the valley no pebbles could be found which were scratched. Up the valley a few miles pebbles were occasionally discovered which showed some slight indications of having been scratched, but which had been subjected to such an amount of abrasion by water-action as almost to erase the scratches. On reaching Ackley's Station, the stream is found to be cutting through a regular terminal moraine, extending across the valley and full of clearly marked glaciated stones. Above this terminal moraine the terraces and gravel ridges which had characterised the valley below disappear, giving place to long stretches of level and swampy land, which had been subject to overflow.

Something similar to this so often appears, that there can be no question as to its meaning, which is, that during the farthest extent of the ice the front rested for a considerable period of time along the line marked by the terminal moraine. During this period there occurred both the accumulation of the moraine and of the gravel terraces in the valley below, due to the vast flow of water emerging from the ice-front, especially during the period when it was most rapidly melting away. Upon the retreat of the ice, the moraine constituted a dam which has not yet been wholly worn away. For a while the water was so effectually ponded back by this as to form a lake, which has since become filled up with sediment and accumulations of peat. From this it is evident, also, that when the ice began to retreat, the retreat was so continuous and rapid that no parallel terminal moraines were formed for many miles.

Before leaving this section we will summarise the leading facts concerning the glacial phenomena north of Pennsylvania and New Jersey. From the observations of Professor Smock, it appears that, from the southern margin the ascent to the summit of the ice-sheet was pretty rapid; the depth one mile back from the margin being

not much less than a thousand feet. "Northward the angle of the slope diminished, and the glacier surface approximated to a great level plain. The distance between the high southwestern peaks of the Catskills and Pocono Knob in Pennsylvania is sixty miles. The difference in the elevation of the glacier could not have exceeded a thousand feet,"* that is, the slope of the surface was about seventeen feet to the mile.

Professor Dana estimates the thickness of the ice in southern Connecticut to have been between fifteen hundred and two thousand feet. Attempts to calculate the thickness of the ice farther north, except from actual discovery of glacial action on the summits of the mountains, are based upon uncertain data with reference to the slope necessary to secure glacial movement. In the Alps the lowest mean slopes down which glaciers move are about two hundred and fifty feet to a mile; but in Greenland, Jensen found the slope of the Frederickshaab Glacier to be only seventy-five feet to the mile, while Helland found that of the Jakobshavn Glacier to be only forty-five feet.

It is doubtful if even that amount is necessary to secure a continental movement of ice, since, as already remarked, it is unsafe to draw inferences concerning the movements of large masses of ice from those of smaller masses in more constricted areas. We have seen, from the glacial deposits on the top of Mount Washington, that over the northern part of New England the ice was more than a mile in depth. We have no direct evidence of the depth of the stream which surrounded the Adirondack Mountains. Nor, on the other hand, are we certain that the Catskills were not completely enveloped in ice, though most observers, reasoning from negative evidence, have supposed that to be the case. But from the facts stated concerning the boulders along the glacial boundary

* American Journal of Science, vol. cxxv, 1883, p. 339 *et seq.*

in Pennsylvania, it is certain that the ice was deep enough to surmount the ridge of the Alleghanies where they are two thousand and more feet in height. At the least calculation the ice must have been five hundred feet thick, in order to secure the movement of which there is evidence across the Appalachian range. Supposing this to be the height of the ice above the sea on the crest of the Alleghanies, and that the slope of the surface of the ice-sheet was as moderate as Professor Smock has estimated it (namely seventeen feet to the mile), the ice would be upwards of six thousand feet in thickness in the latitude of the Adirondacks, which corresponds closely with the positive evidence we have from the mountains in New England.

A study of the map of New York will make it easy to understand the distribution of some interesting glacial marks over the State. The distance along the Hudson from the glacial boundary in the vicinity of New York to the valley of the Mohawk is about one hundred and sixty miles. From the glacial boundary at Salamanca, N. Y., to the same valley, is not over eighty miles. It is easy to see, therefore, that when, in advancing, the ice moved southward past the Adirondacks, the east end of the valley of the Mohawk was reached and closed by the ice, while at the west end of Lake Ontario the ice-front was still in Canada. Thus the drainage, which naturally followed the course of the St. Lawrence, would first be turned through the Mohawk. Afterwards, when the Mohawk had been closed by ice, the vast amount of ponded water was compelled to seek a temporary outlet over the lower passages leading into the Susquehanna or into the Alleghany.

A number of such passages exist. One can be traced along the line of the old canal from Utica to Binghamton, whose highest level is not far from eleven hundred feet. Another lies in a valley leading south of Cayuga

Lake, whose highest point, at Wilseyville, is nine hundred and forty feet above tide. Another leads south to the Chemung River from Seneca Lake, whose highest point, at Horseheads, is less than nine hundred feet above tide. The cols farther west are somewhat more elevated; the one at Portage, leading from the Genesee River into the Canisteo, being upwards of thirteen hundred feet, and that of Dayton, leading from Cattaraugus Creek into the Conewango, being about the same. Of other southern outlets farther west we will speak later on.

Fixing our minds now upon the region under consideration, in the southern part of the State of New York, we can readily see that a glacial lake must have existed in front of the ice while it was advancing, until it had reached the river-partings between the Mohawk and the St. Lawrence Rivers on the north and the Susquehanna and Alleghany Rivers on the south. After the ice had attained its maximum extension, and was in process of retreat, there would be a repetition of the phenomena, only they would occur in the reverse order. The glacial markings which we see are, of course, mainly those produced during the general retreat of the ice.

The Susquehanna River stretching out its arms—the Chenango and Chemung Rivers—to the east and the west, evidently serve as a line of drainage for the vast glacial floods. These floods have left, along their courses, extensive elevated gravel terraces, with much material in them which is not local, but which has been washed out of the direct glacial deposits from the far north. The east-and-west line of the water-parting throughout the State is characterised by excessive accumulations of glaciated material, forming something like a terminal moraine, and is designated by President Chamberlin as "the terminal moraine of the second Glacial epoch," corresponding, as he thinks, to the interior line already described as characterising the south shore of New England.

In the central part of New York the remarkable series of "Finger Lakes," tributary to Lake Ontario and emptying into it through the Oswego and Genesee Rivers, all have a glacial origin. Probably, however, they are not due in any great degree to glacial erosion, but they seem to occupy north-and-south valleys which had been largely formed by streams running towards the St. Lawrence when there was, by some means (probably through the Mohawk River), a much deeper outlet than now exists, but which has been filled up and obliterated by glacial *débris*. The ice-movement naturally centred itself more or less in these north-and-south valleys, and hence somewhat enlarged them, but probably did not deepen them. The ice, however, did prevent them from becoming filled with sediment, and on its final retreat gave place to water.

Between these lakes and Lake Ontario, also, and extending east and west nearly all the way from Syracuse to Rochester, there is a remarkable series of hills, from one hundred to two or three hundred feet in height, composed of glacial *débris*. But while the range extends east and west, the axis of the individual hills lies nearly north and south. These are probably remnants of a morainic accumulation which were made during a pause in the first advance of the ice, and were finally sculptured into their present shape by the onward movement of the ice. These are really "drumlins," similar to those already described in northeastern Massachusetts and southeastern New Hampshire. In the valley of central New York these have determined the lines of drainage of the "Finger Lakes," and formed dams across the natural outlets of nearly all of them.

North of the State of New York the innumerable lakes in Canada are all of glacial origin, being mostly due to depressions of the nature of kettle-holes, or to the damming up of old outlets by glacial deposits. A pretty well-

marked line of moraine hills, formed probably as terminal deposits in the later stages of the Ice age, runs from near the eastern end of Lake Ontario to the Georgian Bay, passing south of Lake Simcoe.

The Mississippi Basin.

The physical geography of the glaciated region north of the Ohio River is so much simpler than that of New England and the Middle States, that its characteristics can be briefly stated. Ohio, Indiana, and Illinois are covered with nearly parallel strata of rock mostly of the Carboniferous age. In general, the surface slopes gently to the west; the average elevation of Ohio being about a thousand feet above tide, while that of the Great Lakes to the north and of the middle portion of the Mississippi Valley is less than six hundred feet. The glacial deposits are spread in a pretty even sheet over the area which was reached by the ice in these States, and the lines of moraine, of which a dozen or more have been partially traced in receding order, are much less clearly marked than they are in New England, or in Michigan, and the States farther to the northwest.

The line marking the southern limit attained by the ice of the Glacial period in these three States is as follows: Entering Ohio in Columbiana County, about ten miles north of the Ohio River, the glacial boundary runs westward through New Lisbon to Canton in Stark County, and thence to Millersburg in Holmes County. A few miles west of this place it turns abruptly south, passing through Danville in Knox County, Newark in Licking County, Lancaster in Fairfield County, to Adelphi in Ross County. Thence bearing more westward it passes through Chillicothe to southeastern Highland County and northwestern Adams, reaching the Ohio River near Ripley, in Clermont County. Thence, following the north bank of the Ohio River to Cincinnati, it crosses the river, and after

extending through the northern part of Boone County, Kentucky, and recrossing the river to Indiana, not far from Rising Sun, it again follows approximately the north bank of the river to within about ten miles of Louisville, Ky., where it bends northward running through Clarke, Scott, Jackson, Bartholomew, and Brown Counties to Martinsville, in Morgan County, where it turns again west and south and follows approximately the West Branch of the White River through Owen, Greene, and Knox Counties, where it crosses the main stream of White River, and, continuing through Gibson and Posey Counties, crosses the Wabash River near New Harmony.

In Illinois the line still continues southwesterly through White, Gallatin, Saline, and Williamson Counties, where it reaches its southern limit near Carbondale, in latitude 37° 40′, and from this point trends northwestward, approximately following the northeastern bluff of the Mississippi River, to the vicinity of Carondelet, Mo., a short distance south of St. Louis.

Beyond the Mississippi the line follows approximately the course of the Missouri River across Missouri, and continues westward to the vicinity of Manhattan, in Kansas, where it turns northward, keeping about a hundred miles west of the Missouri River, through eastern Kansas and Nebraska, and striking the river near the mouth of the Niobrara, in South Dakota. From there the line follows approximately the course of the Missouri River to the vicinity of Fort Benton, in northwestern Montana, where the line again bears more northward, running into British America.

It is still in dispute whether the ice extended from the eastern centre far enough west to join the ice-movement from the Rocky Mountain plateau. Dr. George M. Dawson * is of the opinion that it did not, but that there was

* Transactions of the Royal Society of Canada, vol. viii, sec. iv, pp. 54–74.

a belt of a hundred miles or more, east of the Rocky Mountains, which was never covered by true glacial ice. Mr. Upham * is equally confident that the two ice-movements became confluent, and united upon the western plateau of Manitoba. The opportunity for such a difference of opinion arises in the difficulty sometimes encountered of distinguishing between a direct glacial deposit and a deposit taking place in water containing boulder-laden icebergs. Where Mr. Upham supposes the ice-fields of the east and of the west to have been confluent in western Manitoba, Dr. Dawson supposes there was an extensive subsidence of the land sufficient to admit the waters of the ocean. Leaving this question for the present undetermined, we will now rapidly summarise the glacial phenomena west of the third meridian from Washington (which corresponds nearly with the western boundary of Pennsylvania), and east of the Rocky Mountains.

That the glacial movement extended to the southern boundary just delineated is established by the presence down to that line of all the signs of glacial action, and their absence beyond. Glacial groovings are found upon the freshly uncovered rock surfaces at frequent intervals in close proximity to the line all along its course, while granitic boulders from the far north are scattered, with more or less regularity, over the whole intervening space between this line and the Canadian highlands. I have already referred to a boulder of jasper conglomerate found in Boone County, Kentucky, which must have come from unique outcroppings of this rock north of Lake Huron. Granitic boulders from the Lake Superior region are also found in great abundance at the extreme margin mentioned in southern Illinois. West of the Missouri River it is somewhat more difficult to delineate the boundary

* American Geologist, vol. vi, September, 1890; Bulletin of the Geological Society of America, vol. ii, pp. 243–276.

with accuracy, on account of an enveloping deposit of fine loam, technically called "loess." Loess is very abundant in the whole valley of the Missouri River below Yankton, South Dakota, being for a long distance in the vicinity of the river a hundred feet or more in depth. Over northern Missouri and southern Illinois the deposit is nearly continuous, but less in depth, and everywhere in that region tends to hide from view the unstratified glacial deposit continuously underlying it.

A single instance of personal experience will illustrate the condition of things. While going south from Chicago, in search of the southern limit of glacial action, I stopped off from the train at Du Quoin, about forty miles north of where I subsequently found the boundary. Here the whole surface was covered with loess, two or three feet in depth. Below this was a gravelly soil, three or four feet in thickness, which contained many scratched pebbles of granite. A well which had recently been dug, reached the rock at a depth of twenty feet, and revealed a beautifully polished and scratched surface, betraying, beyond question, the action of glacial ice. As we shall show a little later, it is probable that, about the time the ice of the Glacial period had reached its maximum development, this area, which is covered with loess, was depressed in level, and remained under water during a considerable portion of the period when the ice-front was retreating.

To such an extent is this portion of the area included in southern Iowa, northern Missouri, southern Illinois, and the extreme southern portions of Indiana and Ohio covered with loess, that it has been difficult to determine the relation of its underlying glacial deposits to the more irregular deposits found farther north. At an early period of recent investigations, while making a geological survey of the State of Wisconsin, President T. C. Chamberlin fixed upon the line of moraine hills, which can be seen upon our map, running southward between Green Bay

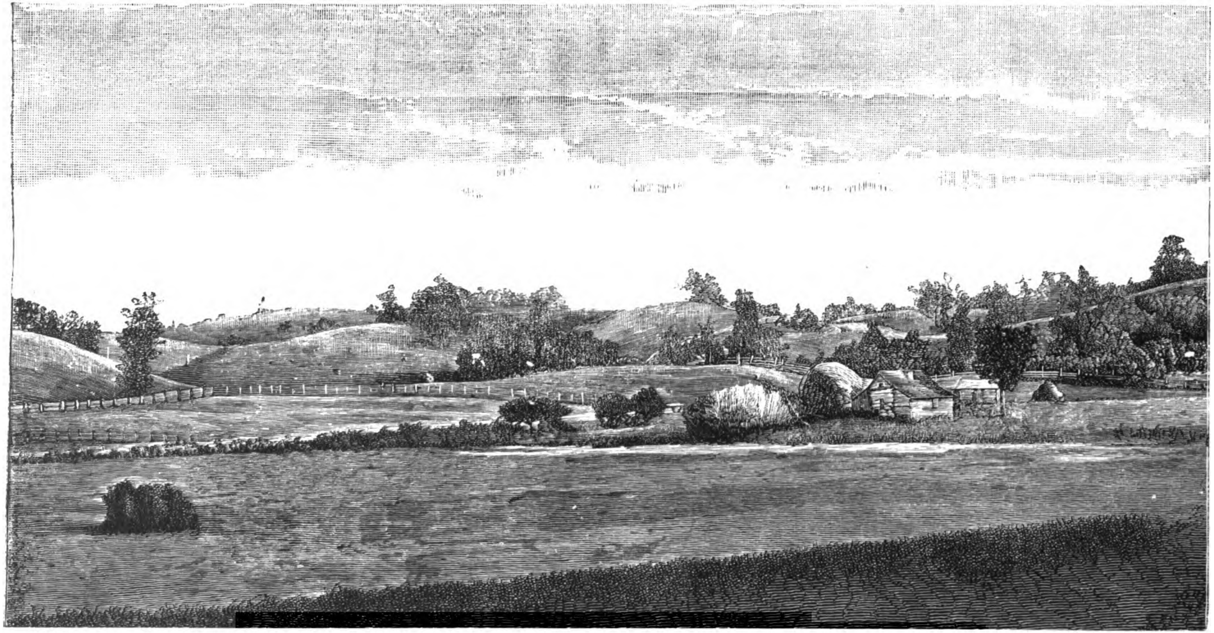

Fig. 33.—Western face of the kettle-moraine, near Eagle, Waukesha County, Wisconsin.
(From photograph by President T. C. Chamberlin, United States Geological Survey.)

and Lake Michigan, and sweeping around in a curve to the right, passing south of Madison and northward along the line of Wisconsin River, and in another curve to the left, around the southern end of Lake Michigan, as the "terminal moraine of the second Glacial epoch." In Wisconsin the character of this line of moraine hills had been discovered and described by Colonel Charles Whittlesey, in 1866. It was first named the "kettle-moraine," because of the frequent occurrence in it of "kettle-holes." This line of moraine hills has been traced with a great degree of confidence across the entire glaciated area, as shown upon our map, but it is not everywhere equally distinct, and, as will be observed, follows a very irregular course.

Beginning in Ohio we find it coinciding nearly with the extreme glacial boundary until it reaches the valley of the Scioto River, on the sixth meridian west from Washington, where it begins to bear northward and continues in that direction for a distance of sixty or seventy miles, and then turns southward again in the valley of the Miami, having formed between these two valleys a sort of medial moraine.* A similar medial moraine had also been noted by President Chamberlin between the valleys of the Grand and Cuyahoga Rivers, in the eastern part of Ohio. Indeed, for the whole distance across Ohio and Indiana, this moraine occurs in a series of loops pointing to the south, corresponding in general to the five gentle valleys which mark the territory, namely, those of the Grand and Mahoning Rivers; the Sandusky and Scioto Rivers; the Great Miami River; the White River; and the Maumee and Wabash Rivers. Everywhere, however, over this area these morainic accumulations approximate pretty closely to the extreme boundary of the glaciated region.

In Illinois President Chamberlin's original determination of the moraine fixed it near the southern end of Lake

* See map at the beginning of the chapter.

Michigan, as shown upon our map, but Mr. Frank Leverett has subsequently demonstrated that there is a concentric series of moraines south of this, reaching across the State, (but somewhat obscured by superficial accumulations of loess referred to) and extending nearly to the latitude of St. Louis.

West of Wisconsin President Chamberlin's "terminal moraine of the second Glacial epoch" bends southward through eastern Minnesota, and, sweeping down through central Iowa, forms, near the middle of the northern part of that State, a loop, having its southern extremity in the vicinity of Des Moines. The western arm of this loop runs through Minnesota in a northwesterly direction nearly parallel with the upper portion of the valley of the Minnesota, until reaching the latitude of the head-waters of that river, where, in the vicinity of the Sisseton Agency, in Dakota, it turns to the south by an acute angle, and makes a loop in that State, extending to the vicinity of Yankton, and with the valley of the James River as its axis. The western arm of this loop follows pretty closely the line of the eastern edge of the trough of the Missouri River, constituting what is called the "Missouri Coteau," which continues on as a well-marked line of hills running in a northwesterly direction far up into the Dominion of Canada.

One of the most puzzling glacial phenomena in the Mississippi Valley is the driftless area which occupies the southeastern portion of Minnesota, the southwestern part of Wisconsin, and the northwestern corner of Iowa, as delineated upon our map. This is an area which, while being surrounded on every side by all the characteristic marks of glaciation, is itself conspicuous for their entire absence. Its rocks preserve no glacial scratches and are covered by no deposits of till, while northern boulders avoided it in their journey to more southern latitudes.

The reason for all this is not evident in the topography

of the region. The land is not higher than that to the north of it, nor is there any manifest protection to it by the highlands south of Lake Superior. Nor yet is there any reason to suppose that any extensive changes of level in former times seriously affected its relations to the surrounding country. Professor Dana, however, has called attention to the fact that even now it is in a region of comparatively light precipitation, suggesting that the snow-fall over it may always have been insignificant in amount. But this could scarcely account for the failure of the great ice-wave of the north to overrun it. We are indebted again to the sagacity of President Chamberlin in suggesting the true explanation.

By referring to the map it will be noticed that this area sustains a peculiar relation to the troughs of Lake Michigan and Lake Superior, while from the arrangements of the moraines in front of these lakes it will be seen that these lake basins were prominent factors in determining the direction of the movement of the surplus ice from the north. It is the more natural that they should do so because of their great depth, their bottoms being in both cases several hundred feet below the present water-level, reaching even below the level of the sea.

These broad, deep channels seem to have furnished the readiest outlet for the surplus ice of the North, and so to have carried both currents of ice beyond this driftless area before they became again confluent. The slight elevation south of Lake Superior served to protect the area on account of the feebleness of direct movement made possible by the strength of these diverging lateral ice-currents. The phenomenon is almost exactly what occurs where a slight obstruction in a river causes an eddy and preserves a low portion of land below it from submergence. A glance at the map will make it easily credible that an ice-movement south of Manitoba, becoming confluent with one from Lake Superior, pushed far down into the Mis-

souri Valley and spread eastward to the Mississippi River, south of the glaciated driftless area, and there became confluent with a similar movement which had been directed by the valleys of Lake Michigan and Lake Erie. There can be little doubt that President Chamberlin's explanation is in the main correct, and we have in this another illustration of the analogy between the behaviour of moving ice and that of moving water.

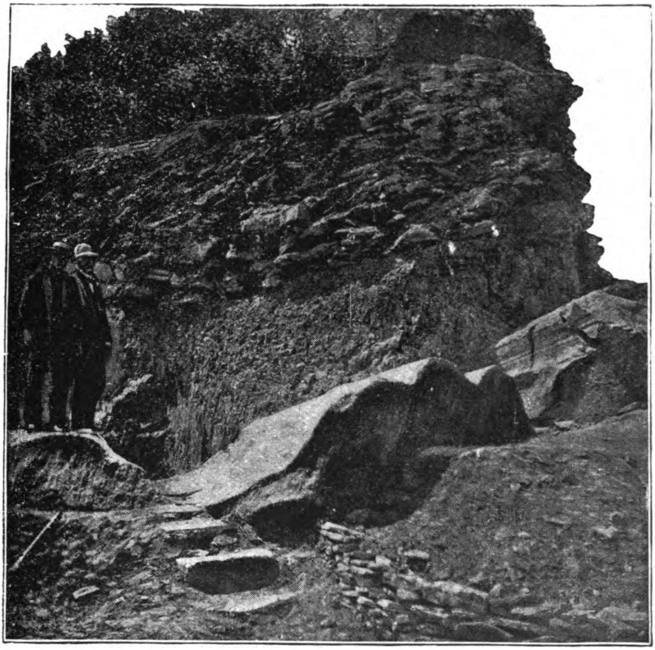

FIG. 34.—Section of the east-and-west glacial furrows, on Kelly's Island, preserved by Mr. Younglove. Fine sediment rests immediately on the rock, with washed pebbles at the surface.

The accompanying illustrations will give a better idea than words can do of the celebrated glacial grooves on the hard limestone islands near Sandusky, in the western part

of Lake Erie. Through the interest aroused in them by an excursion of the American Association for the Advancement of Science, while meeting in Cleveland, Ohio, in 1888, the Kelly Island Lime and Transport Company, of which Mr. M. C. Younglove is the president, has been induced to deed to the Western Reserve Historical Society for preservation a portion of one of the most remarkable of the grooves still remaining.

The portion of the groove preserved is thirty-three feet across, and the depth of the cut in the rock is seventeen feet below the line, extending from rim to rim. Originally there was probably here a small depression formed by preglacial water erosion, into which the ice crowded the material, which became its graving-tool, and so the rasping and polishing went on in increasing degree until this enormous furrow is the result. The groove, however, is by no means simple, but presents a series of corrugations merging into each other by beautiful curves. When exposed for a considerable length it will resemble nothing else so much as a collection of prostrate Corinthian columns lying side by side on a concave surface.

The direction of these grooves is a little south of west, corresponding to that of the axis of the lake. This is nearly at right angles to the course of the ice-scratches on the summit of the water-shed south of this, between the lake and the Ohio River. The reason for this change of direction can readily be seen by a little attention to the physical geography. The highlands to the south of the lake rise about seven hundred feet above it. When the Ice period was at its climax and overran these highlands, the ice took its natural course at right angles to the terminal moraine and flowed southeast according to the direction indicated by the scratches on the summit; but when the supply of ice was not sufficient to overrun the highlands, the obstruction in front turned the course and the resultant was a motion towards Toledo and the Maumee

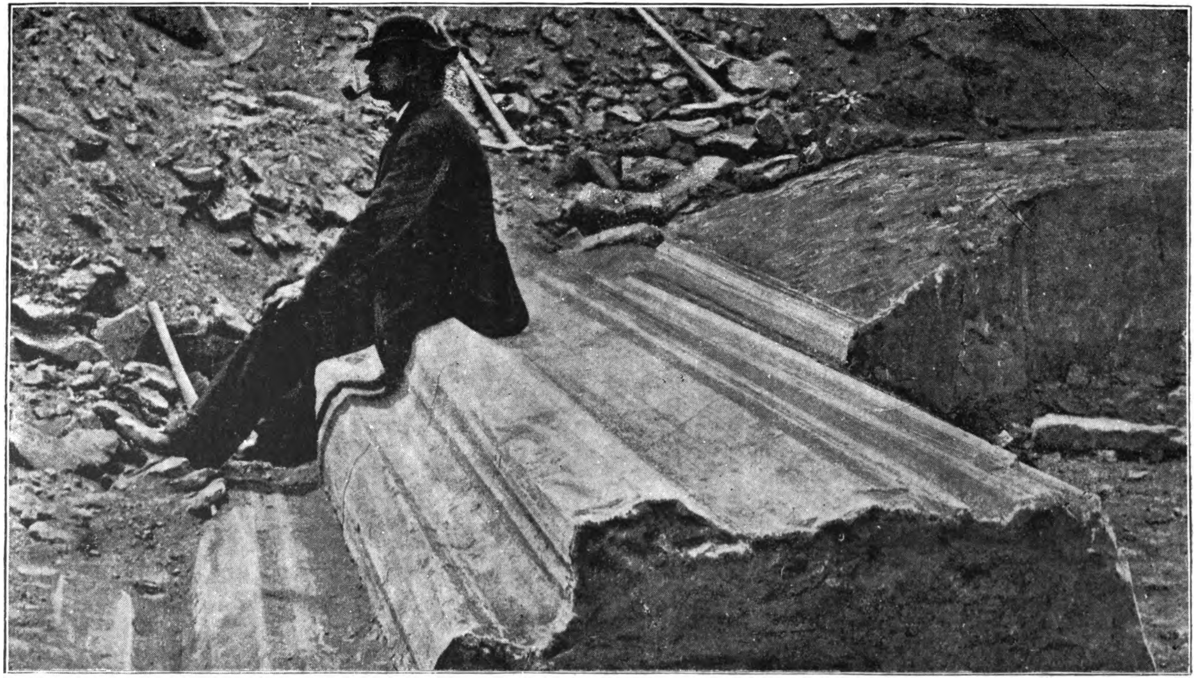

Fig. 35.—Same as the preceding. (Courtesy of M. C. Younglove.)

Valley, where in the vicinity of Fort Wayne an extensive terminal moraine was formed.

The much-mooted question of a succession of glacial epochs finds the most of its supporting facts in the portion of the glaciated area lying west of Pennsylvania. That there have been frequent oscillations of the glacial front over this area is certain. But it is a question whether the glacial deposits south of this distinct line of moraine hills are so different from those to the north of it as to necessitate the supposition of two entirely distinct glacial epochs. This can be considered most profitably here.

The following are among the points with reference to which the phenomena south of the moraine just delineated differ from those north of the line:

1. The glacial deposits to the south appear to be distributed more uniformly than those to the north. To the north the drift is often accumulated in hills, and is dotted over with kettle-holes, while to the south these are pretty generally absent. Any one travelling upon a line of railroad which traverses these two portions of the glaciated area as indicated upon our map can easily verify these statements.

2. The amount of glacial erosion seems to be much less south of the line of moraine hills delineated than north of them. Still, glacial striæ are found, almost everywhere, close down to the extreme margin of the glaciated area.

3. The gravel deposits connected with the drainage of the Glacial period are much less abundant south of the so-called "terminal moraine of the second Glacial period" than they are north of it. South of this moraine the water deposits attributed to the Glacial period are of such fine silt as to indicate slow-moving currents over a gentle low slope of the surface.

4. The glacial deposits to the south are more deeply

coloured than those to the north, showing that they have been longer exposed to oxidising agencies. Even the granitic boulders show the marks of greater age south of this line, being disintegrated to a greater extent than those to the north.

5. And, finally, there occur, over a wide belt bordering the so-called moraine hills of the second Glacial epoch, extensive intercalated beds of vegetal deposits. Among the earliest of these to be discovered were those of Montgomery County, Ohio, where, in 1870, Professor Orton, of the Ohio Survey, found at Germantown a deposit of peat fourteen feet thick underneath ninety-five feet of till, and there seem also to be glacial deposits underneath the peat as well as over it. The upper portion of the peat contains "much undecomposed sphagnous mosses, grasses, and sedges, and both the peat and the clayey till above it" contain many fragments of coniferous wood which can be identified as red cedar (*Juniperus Virginianus*). In numerous other places in that portion of Ohio fresh-appearing logs, branches, and twigs of wood are found underneath the till, or mingled with it, much as boulders are. Near Darrtown, in Butler County, Ohio, red cedar logs were found under a covering of sixty-five feet of till, and so fresh that the perfume of the wood is apparently as strong as ever. Similar facts occur in several other counties in the glaciated area of southern Ohio and southern Indiana. Professor Collett reports that all over southwestern Indiana peat, muck, rotted stumps, branches, and leaves of trees are found from sixty to one hundred and twenty feet below the surface, and that these accumulations sometimes occur to a thickness of from two to twenty feet.

Farther to the northwest similar phenomena occur. Professor N. H. Winchell has described them most particularly in Fillmore and Mower Counties, Minnesota, from which they extend through a considerable portion of

Iowa. In the above counties of Minnesota a stratum of peat from eighteen inches to six or eight feet in thickness, with much wood, is pretty uniformly encountered in dig-

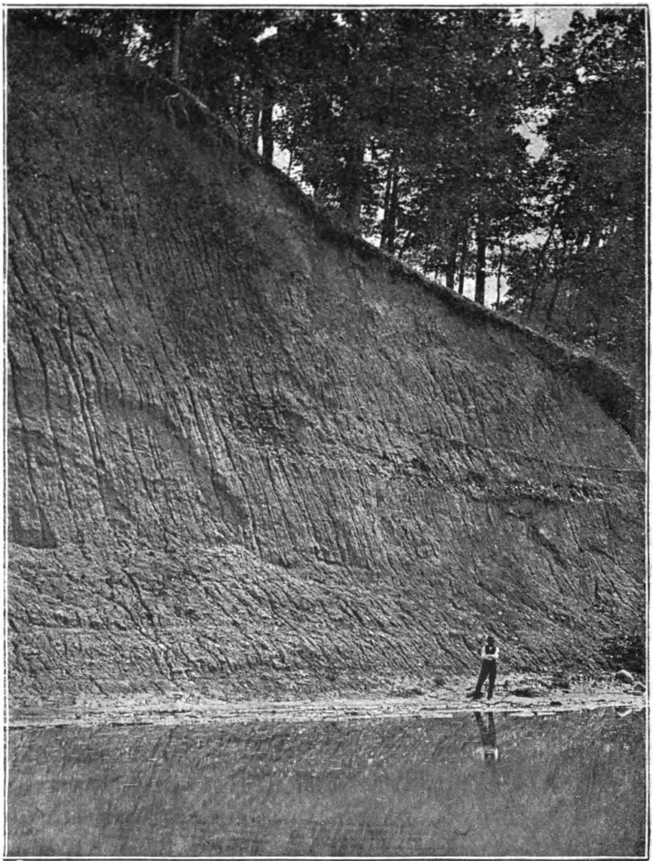

FIG. 36.—Section of till near Germantown, Ohio, overlying thick bed of peat. The man in the picture stands upon a shelf of peat from which the till has been eroded by the stream. The dark spot at the right hand of the picture, just above the water, is an exposure of the peat. The thickness of the till is ninety-five feet. The partial stratification spoken of in the text can be seen about the middle of the picture. The furrows up and down had been made by recent rains. (United States Geological Survey.) (Wright.)

ging wells, the depth varying from twenty to fifty feet. This county is near the highest divide in the State of Minnesota, and from it "flow the sources of the streams to the north, south, and east." The wood encountered in this stratum indicates the prevalence of coniferous trees, and the peat mosses indicate a cool and moist climate.

Nor are intercalated vegetable deposits absent from the vast region farther north over the area that drains into Hudson Bay. At Barnesville, in Clay County, Minnesota, which lies in the valley of the Red River of the North, and also in Wilkin County in the same valley, tamarack wood and sandy black mud containing many snail-shells have been found from eight to twelve feet below a surface of till; and Dr. Robert Bell reports the occurrence of limited deposits of lignite between layers of till, far to the northwest, in Canada, and even upon the southern part of Hudson Bay; while Mr. J. R. Tyrrell reports * many indications of successive periods of glaciation near the northern end of the Duck Mountain. The most characteristic indications which he had witnessed consisted of stratified beds of silt, containing fresh-water shells, with fragments of plants and fish similar to those living in the lakes of the region at the present time.

Reviewing these facts with reference to their bearing upon the point under consideration, we grant, at the outset, that they do indicate a successive retreat and readvance of the ice over extensive areas. This is specially clear with respect to the vegetal deposits interstratified with beds of glacial origin. But the question at issue concerning the interpretation of these phenomena is, Do they necessarily indicate absolutely distinct glacial epochs separated by a period in which the ice had wholly disappeared from the glaciated area to the north? That they

* Bulletin of the Geological Society of America, vol. i, pp. 395–410.

do, is maintained by President Chamberlin and many others who have wide acquaintance with the facts. That they do not certainly indicate a complete disappearance of the ice during an extensive interglacial epoch, is capable, however, of being maintained, without forfeiting one's rights to the respect of his fellow-geologists. The opposite theory is thus stated by Dr. Robert Bell: "It appears as if all the phenomena might be referred to one general Glacial period, which was long continued, and consequently accompanied by varying conditions of temperature, regional oscillations of the surface, and changes in the distributions of sea and land, and in the currents in the ocean. These changes would necessarily give rise to local variations in the climate, and might permit of vegetation for a time in regions which need not have been far removed from extensive glaciers.*

At my request, Professor J. E. Todd, of Iowa, whose acquaintance with the region is extensive, has kindly written out for me his conclusions upon this subject, which I am permitted to give in his own words:

"I am not prepared to write as I would like concerning the forest-beds and old soils. I will, however, offer the following as a partial report. I have come to think that there is considerable confusion on the subject. I believe there are five or six different things classed under one head.

"1. *Recent Muck and Soils.*—The finest example I have found in the whole Missouri Valley was twenty feet below silt and clay, in a basin inside the outer moraine, near Grand View, South Dakota. From my examination of the reported old soil near Albia, Iowa, I think the most rational way of reconciling the conflicting statements concerning it is that it also belongs to this class.

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* Bulletin of the Geological Society of America, vol. i, pp. 287–310.

"2. *Peat or Soil under Loess.*—This does not signify much if the loess was formed in a lake subject to orographic oscillations, or if, as I am coming to believe, it is a fluviatile deposit of an oscillating river like the Hoang-Ho on the great Chinese plain. It at least does not mean an interglacial epoch.

"3. *Wood and Dirt rearranged, not in situ.*—This occurs either in subaqueous or in subglacial deposits. I have found drift-wood in the lower layers of the loess here, but not *in situ*. I have frequently found traces of wood in till in Dakota, but always in an isolated way. I think, from reading statements about the deposits in eastern Iowa, that most if not all of the cases are of this sort. Two things have conspired to lead to this error: one, the influence of Croll's speculation; and the other, the easy inference of many well-diggers, and especially well-borers, that what they pass through are always in layers. In this way a log becomes a forest-bed. Scattered logs and muck fragments occurring frequently in a region, though at different levels, are readily imagined by an amateur geologist to be one continuous stratum antedating the glacier or floods (as the case may be in that particular region), when, in fact, it has been washed down from the margin of the transporting agent and is contemporaneous with it. I suspect the prevalence of wood in eastern Iowa may be traced to a depression of the driftless region during the advance of the glacier, so as to bring the western side of that area more into the grasp of glacial agencies.

"4. *Peat between Subglacial Tills.*—If cases of this sort are found, they are in Illinois, Indiana, and Ohio. Professor Worthen insisted that there were no interglacial soils or forest-beds in Illinois; and in the cases mentioned in the State reports he repeatedly explains the sections given by his assistants, so as to harmonize them with that statement. I think he usually makes his explanations

plausible. He was very confident in referring most of them to preglacial times. His views, I suppose, will be published in the long-delayed volume, now about to be issued.

"5. *Vegetable Matter between Glacial Till and Underlying Berg Till or other Drift Deposits.*—When one remembers that the front of the great ice-sheet may have been as long in reaching its southern boundary as in receding from it, and with as many advance and retrograde movements, we can easily believe that much drift material would have outrun the ice and have formed deposits so far ahead of it that vegetation would have grown before the ice arrived to bury it.

"6. *Preglacial Soils, etc.*—I believe that this will be found to include most in southern Ohio, if not in Illinois, as Worthen claimed."

The phenomena of the Glacial period are too vast either to have appeared or to have disappeared suddenly. By whatever cause the great accumulation of ice was produced, the advance to the southward must have been slow and its disappearance must have been gradual, though, as we shall show a little later, the final retreat of the ice-front occupied but a short time relatively to the whole period which has elapsed since. As we shall show also, the advent of the Ice period was probably preceded and accompanied by a considerable elevation of the northern part of the continent Whether this elevation was contemporaneous upon both sides of the continent is perhaps an open question; but with reference to the area east of the Rocky Mountains, which is now under consideration, the centre of elevation was somewhere south of Hudson Bay. Putting together what we know, from the nature of the case, concerning the accumulation and movement of glacial ice, and what we know from the relics of the great glacial invasion, which have enabled us to determine its extent and the vigour of its action, the course of events seems to have been about as follows:

Throughout the Tertiary period a warm climate had prevailed over British America, Greenland, and indeed over all the lands in proximity to the north pole, so far as explorers have been able to penetrate them. The vegetation characterizing these regions during the Tertiary period indicates a temperature about like that which now prevails in North Carolina and Virginia. Whatever may be said in support of the theory that the Glacial period was produced by astronomical causes, in view of present facts those causes cannot be regarded as predominant; at most they were only co-operative. The predominant cause of the Glacial period was probably a late Tertiary or post-Tertiary elevation of the northern part of the continents, accompanied with a subsidence in the central portion. Of such a subsidence in the Isthmus of Panama indications are thought to be afforded by the occurrence of late Tertiary or, more probably, post-Tertiary sea-shells at a considerable elevation on the divide along the Isthmus of Panama, between the Atlantic and Pacific Oceans. Of this we shall speak more fully in a later chapter.

Fixing our thoughts upon what is known as the Laurentian plateau, which, though now in the neighbourhood of but two thousand feet above the sea, was then much higher, we can easily depict in imagination the beginnings of the great "Laurentide Glacier," which eventually extended to the margin already delineated on the south and southwest in the United States, and spread northward and eastward over an undetermined area. Year after year and century after century the accumulating snows over this elevated region consolidated into glacial ice and slowly pushed outward the surplus reservoirs of cold. For a long time this process of ice-accumulation may have been accompanied by the continued elevation of the land, which, together with the natural effect of the enlarging area of ice and snow, would tend to lower the

temperature around the margin and to increase still more the central area of accumulation.

The vigour of movement in any direction was determined partly by the shape of the valleys opening southward in which the ice-streams would naturally concentrate, and partly by those meteorological conditions which determine the extent of snow-fall over the local centres of glacial dispersion. For example, the general map of North America in the Ice period indicates that there were two marked subcentres of dispersion for the great Laurentide Glacier, the eastern one being in Labrador and the western one north of Lake Superior. In a general way the southern boundary of the glaciated region in the United States presents the appearance of portions of two circumferences of circles intersecting each other near the eastern end of Lake Erie. These circles, I am inclined to believe, represent the areas over which a semi-fluid (or a substance like ice, which flows like a semi-fluid) would disperse itself from the subcentres above mentioned.

A study of the contour of the country shows that that also, in a general way, probably had something to do with the lines of dispersion. The western lobe of this glaciated area corresponds in its boundary pretty closely with the Mississippi Valley, having the Ohio River approximately as its eastern arm and the Missouri as its western, with the Mississippi River nearly in its north and south axis. The eastern lobe has its farthest extension in the axis of the Champlain and Hudson River Valleys, its western boundary being thrown more and more northward as the line proceeds to the west over the Alleghany Mountains until reaching the longitude of the eastern end of Lake Erie; but this southern boundary is by no means a water-level, nor is the contour of the country such that it could ever have been a water-level. But it conforms in nearly every particular to what would be the resultant arising

from a pretty general southward flow of a semi-fluid from the two subcentres mentioned, meeting with the obstructions of the Adirondacks in northern New York and of the broader Appalachian uplift in northern Pennsylvania.

How far south the area of glacial accumulation may have extended cannot be definitely ascertained, but doubtless at an early period of the great Ice age the northern portions of the Appalachian range in New York, New England, New Brunswick, and Nova Scotia became themselves centres of dispersion, while only at the height of the period did all their glaciers become confluent, so that there was one continuous ice-sheet.

In the western portion of the area covered by the Laurentide Glacier, the depression occupied by the Great Lakes, especially Lakes Michigan and Superior, evidently had a marked influence in directing the flow of ice during the stages which were midway between the culmination of the Ice period and both its beginning and its end. This would follow from the great depth of these lakes, the bottom of Lake Michigan being 286 feet below sea-level, and that of Lake Superior 375 feet, making a total depth of water of about 900 and 1,000 feet respectively. Into these oblong depressions the ice would naturally gravitate until they were filled, and they would become the natural channels of subsequent movement in the direction of their longest diameters, while the great thickness of ice in them would make them the conservative centres of glacial accumulation and action after the ice had begun to retreat.

These deductions from the known nature of ice and the known topography of the region are amply sustained by a study of the detailed map showing the glacial geology in the United States. But on this we can represent indeed only the marks left by the ice at various stages of its retreat, since, as already remarked, the marks of each stage of earlier advance would be obliterated by later for-

ward movements. We may presume, however, that in general the marks left by the retreating ice correspond closely with those actually made and obliterated by the advancing movement.

From observations upon the glaciers of Switzerland and of Alaska, it is found that neither the advance nor the retreat of these glaciers is constant, but that, in obedience to meteorologic agencies not fully understood, they advance and retreat in alternate periods, at one time receding for a considerable distance, and at other times regaining the lost ground and advancing over the area which has been uncovered by their retreat.

"M. Forel reports, from the data which he has collected with much care, that there have been in this century five periods in the Alpine glaciers: of enlargement, from 1800 (?) to 1815; of diminution, from 1815 to 1830; of enlargement, from 1830 to 1845; of diminution, from 1845 to 1875; and of enlargement again, from 1875 onward. He remarks further that these periods correspond with those deduced by Mr. C. Lang for the variations for the precipitations and temperature of the air; and, consequently, that the enlargement of the glaciers has gone forward in the cold and rainy period, and the diminution in the warm and the dry."*

When, now, we attentively consider the combination of causes necessary to produce the climatic conditions of the great Ice age of North America, we shall be prepared to find far more extensive variations in the progress of the continental glacier, both during its advance and during its retreat, than are to be observed in any existing local glaciers.

With respect to the arguments adduced in favor of a succession of glacial epochs in America the following criticisms are pertinent:

* American Journal of Science, vol. cxxxii, 1886, p. 77.

1. So far as we can estimate, a temporary retreat of the front, lasting a few centuries, would be sufficient to account for the vegetable accumulations that are found buried beneath the glacial deposits in southern Ohio, Indiana, central Illinois, and Iowa, while a temporary re-advance of the ice would be sufficient to bury the vegetable remains beneath a freshly accumulated mass of till. Thus, as Dr. Bell suggested, the interglacial vegetal deposits do not necessarily indicate anything more than a temporary oscillation of the ice-front, and do not carry with them the necessity of supposing a disappearance of the ice from the whole glaciated area. Thus the introduction of a whole Glacial period to account for such limited phenomena is a violation of the well-known law of parsimony, which requires us in our explanations of phenomena to be content with the least cause which is sufficient to produce them. In the present instance a series of comparatively slight oscillations of the ice-front during a single glacial period would seem to be sufficient to account for all the buried forests and masses of vegetal *débris* that occur either in the United States or in the Dominion of Canada.

2. Another argument for the existence of two absolutely distinct glacial periods in North America has been drawn from the greater oxidation of the clays and the more extensive disintegration of certain classes of the boulders found over the southern part of the glaciated area of the Mississippi Valley, than has taken place in the more northerly regions. Without questioning this statement of fact (which, however, I believe to be somewhat exaggerated), it is not difficult to see that the effects probably are just what would result from a single long glacial period brought about by such causes as we have seen to be probably in operation in America. For if one reflects upon the conditions existing when the Glacial period began, he will see that, during the long ages of warm cli-

mate which characterised the preceding period, the rocks must have been extensively disintegrated through the action of subaërial agencies. The extent to which this disintegration takes place can be appreciated now only by those who reside outside of the glaciated area, where these agencies have been in uninterrupted action. In the Appalachian range south of the glaciated region the granitic masses and strata of gneiss are sometimes found to be completely disintegrated to a depth of fifty or sixty feet; and what seem to be beds of gravel often prove in fact to be horizontal strata of gneiss from which the cementing material has been removed by the slow action of acids brought down by the percolating water.

Now, there can be no question that this process of disintegration had proceeded to a vast extent before the Glacial period, so that, when the ice began to advance, there was an enormous amount of partially oxidised and disintegrated material ready to be scraped off with the first advance of ice, and this is the material which would naturally be transported farthest to the south; and thus, on the theory of a single glacial period, we can readily account for the greater apparent age of the glacial *débris* near the margin. This *débris* was old when the Glacial period began.

3. With reference to the argument for two distinct glacial periods drawn from the smaller apparent amount of glacial erosion over the southern part of the glaciated area, we have to remark that that would occur in case of a single ice-invasion as well as in case of two distinct ice-invasions, in which the later did not extend so far as the former.

From the very necessity of the case, glacial erosion diminishes as the limit of the extent of the glaciation is approached. At the very margin of the glacier, motion has ceased altogether. Back one mile from the margin only one mile of ice-motion has been active in erosion,

while ten miles back from its front there has been ten times as much moving ice actually engaged in erosion, and in the extreme north several hundred times as much ice. Thus it is evident that we do not need to resort to two glacial periods to account for the relatively small amount of erosion exhibited over the southern portion of our glaciated area.

At the same time, it should be said that the indications of active glacial erosion near the margin are by no means few or small. In Lawrence County, Pennsylvania, on the very margin of the glaciated area, Mr. Max Foshay * has discovered very extensive glacial grooves, indicating much vigour of ice-action even beyond the more extensive glacial deposits which Professor Lewis and myself had fixed upon as the terminal moraine. In Highland and Butler Counties, Ohio, and in southwestern Indiana and southern Illinois, near the glacial margin, glacial grooves and striæ are as clear and distinct in many cases as can anywhere be found; while upon the surface of the limestone rocks within the limits of the city of St. Louis, where the glacial covering is thin, and where disintegrating agencies had had special opportunities to work, I found very clear evidences of a powerful ice-movement, which had planed and scratched the rock surface; and at Du Quoin, Illinois, as already related, the fragments thrown up from the surface of the rock, fifty or sixty feet below the top of the soil, were most beautifully planed and striated. It should be observed, also, that this whole area is so deeply covered with *débris* that the extent of glacial erosion underneath is pretty generally hid from view.

4. The uniformity of the distribution of the glacial deposits over the southern portion of the glaciated area in the Mississippi Valley is partly an illusion, due to the

* Bulletin of the Geological Society, vol. ii, pp. 457–464.

fact that there was a vast amount of deposition by water over that area during the earlier stages of the ice-retreat. This has been due partly to the gentler slope which would naturally characterise the borders of an area of elevation, and partly to an extensive subsidence which seems to have begun soon after the ice had reached its farthest extent of motion.

It should be borne in mind that at all times a glacier is accompanied by the issue of vast streams of water from its front, and that these of course increase in volume when the climax has been reached and the ameliorating influences begin to melt away the accumulated mass of ice and to add the volume of its water to that produced by ordinary agencies. As these subglacial streams of water poured out upon the more gentle slopes of the area in front of the ice, they would distribute a vast amount of fine material, which would settle into the hollow places and tend to obscure the irregularities of the previous direct glacial deposit.

Such an instance came clearly under my own observation in the vicinity of Yankton, in South Dakota, where, upon visiting a locality some miles from any river, and to which workmen were resorting for sand, I found that the deposit occupied a kettle-hole, filling it to its brim, and had evidently been superimposed by a temporary stream of water flowing over the region while the ice was still in partial occupation of it. Thus, no doubt, in many cases, the original irregularities of the direct glacial deposits have been obliterated, even where there has been no general subsidence.

But, in the area under consideration, the loess, or loam, is so extensive that it is perhaps necessary to suppose that the central portions of the Mississippi Valley were subjected to a subsidence amounting to about five hundred feet; so that the glacial streams from the retreating ice-front met the waters of the ocean in southern

Illinois and Indiana; thus accounting for the extensive fine silt which has done so much over that region to obscure the glacial phenomena.

West of the Rocky Mountains.

The glacial phenomena in the United States west of the Rocky Mountains must be treated separately, since American geologists have ceased to speak of an all-pervading ice-cap extending from the north pole. But, as already said, the glaciation of North America has proceeded from two definite centres of ice-accumulation, one of which we have been considering in the pages immediately preceding. The great centre of glacial dispersion east of the Rocky Mountains is the region south of Hudson Bay, and the vast ice-field spreading out from that centre is appropriately named the Laurentide Glacier. The movement of ice in this glacial system was outward in all directions from the Laurentian hills, and extended west several hundred miles, well on towards the eastern foot of the Rocky Mountains.

The second great centre of glacial dispersion occupies the vast Cordilleran region of British Columbia, reaching from the Rocky Mountains on the northeast to the Coast Range of the Pacific on the southwest, a width of four hundred miles. The length is estimated by Dr. Dawson to be twelve hundred miles. The principal centre of ice-accumulation lies between the fifty-fifth and the fifty-ninth parallel. From this centre the movement was in all directions, but chiefly to the northwest and to the south. The movement of the Cordilleran glaciers extended northwest to a distance of three hundred and fifty miles, leaving their moraines far down in the Yukon Valley on the Lewes and Pelly Rivers.* Southward the

* See George M. Dawson, in Science, vol. xi, 1888, p. 186, and American Geologist, September, 1890, pp. 153–162.

Cordilleran Glacier moved to a distance of six hundred miles, extending to the Columbia River, in the eastern part of the State of Washington.

From this centre, also, the ice descended to the sea-level upon the west, and filled all the channels between Vancouver's Island and the mainland, as well as those in the Alexander Archipelago of Alaska. South of Vancouver's Island a glacier pushed out through the straits of Juan de Fuca to an unknown distance. All the islands in Puget Sound are composed of glacial *débris*, resembling in every respect the terminal moraines which have been described as constituting many of the islands south of the New England coast. The ice-movement in Puget Sound, however, was probably northward, resulting from glaciers which are now represented by their diminutive descendants on the flanks of Mount Rainier.

South of the Columbia River the country was never completely enveloped by the ice, but glaciers extended far down in the valleys from all the lofty mountain-peaks. In Idaho there are glacial signs from the summit of the Rocky Mountains down to the westward of Lake Pend d'Oreille. In the Yellowstone Park there are clear indications that the whole area was enveloped in glacial ice. An immense boulder of granite, resting upon volcanic deposits, may be found a little west of Inspiration Point, on the Yellowstone Cañon. Abundant evidences of glacial action are also visible down the Yellowstone River to the vicinity of Livingston, showing that that valley must have been filled with glacial ice to a depth of sixteen hundred feet. To the west the glaciers from the Yellowstone Park extended to the border of Idaho, where a clearly marked terminal moraine is to be found in the Tyghee Pass, leading over from the western fork of the Madison River into Lewis Fork of the Snake River. South of Yellowstone Park the Teton Mountains were an important centre for the dispersion of local glaciers, but they did not descend

upon the western side much below the 6,000-foot level, and only barely came to the edge of the great Snake River lava plains. To the east the movement from the Teton Mountains joined that from various other lofty mountains, where altogether they have left a most intricate system of glacial deposits, in whose reticulations Jackson's Lake is held in place.

In Utah extensive glaciers filled all the northern valleys of the Uintah Mountains, and extended westward in the Wahsatch range to the vicinity of Salt Lake City. The mountain region of Colorado, also, had its glaciers,

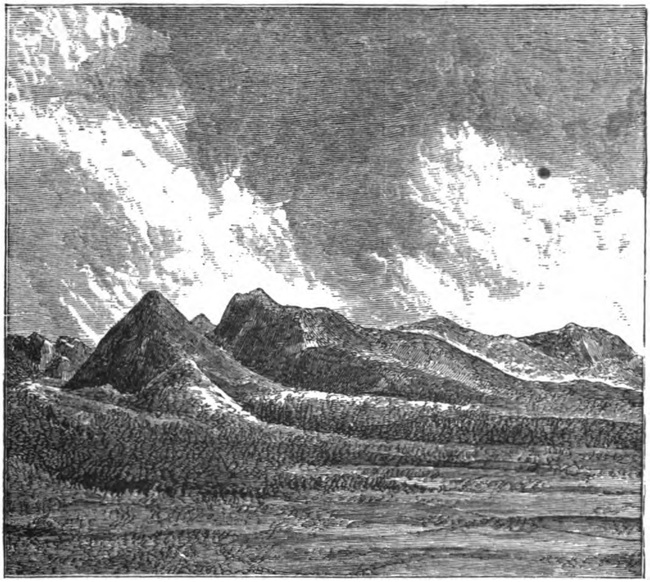

Fig. 37.—Moraines of Grape Creek, Sangre del Cristo Mountains, Colorado (after Stevenson).

occupying the head-waters of the Arkansas, the Platte, the Gunnison, and the Grand Rivers. The most southern point in the Rocky Mountains at which signs of local glaciers have been noted is near the summits of the San

Juan range, in southwestern Colorado. Here a surface of about twenty-five square miles, extending from an elevation of 12,000 feet down to 8,000 feet, shows every sign of the former presence of moving ice. The greater part of the glaciation in Colorado is confined to elevations above 10,000 feet.

The whole range of the Sierra Nevada through Oregon, and as far south as the Yosemite Valley in California, formerly sustained glaciers of far greater size than any which are now found in those mountains. In general these glaciers were much longer on the western side of the Sierra Nevada than on the eastern. On the eastern side glaciers barely came down to Lake Tahoe and Lake Mono in California. The State of Nevada seems to have been entirely free from glaciers, although it contains numerous mountain-peaks more than ten thousand feet high. In the Yosemite Cañon glaciers extended down the Merced River to the mouth of the cañon; while in the Tuolumne River, a few miles to the north, the glaciers which still linger about the peaks of Mount Dana filled the valley for a distance of forty miles.

It is a question among geologists whether or not the glaciation west of the Rocky Mountains was contemporaneous with that of the eastern part of the continent. The more prevalent opinion among those who have made special study of the phenomena is that the development of the Cordilleran glaciers was independent of that of the Laurentide system. At any rate, the intense glaciation of the Pacific coast seems to have been considerably later than that of the Atlantic region. Of this we will speak more particularly in discussing the questions of the date and the cause of the Glacial period. It is sufficient for us here simply to say that, from his extensive field observations throughout the Cordilleran region, Dr. George M. Dawson infers that there have been several successive alternations of level on the Pacific coast corresponding to

successive glacial and interglacial epochs, and that when there was a period of elevation west of the Rocky Mountains there was a period of subsidence to the east, and *vice versa.* In short, he supposes that the east and west for a long time played a game of seesaw, with the Rocky Mountains as the fulcrum. We give his scheme in tabulated form.

Scheme of Correlation of the Phenomena of the Glacial Period in the Cordilleran Region and in the Region of the Great Plains.

CORDILLERAN REGION.	REGION OF THE GREAT PLAINS.
Cordilleran zone at a high elevation. Period of most severe glaciation and maximum development of the great Cordilleran Glacier.	Correlative subsidence and submergence of the great plains, with possible contemporaneous increased elevation of the Laurentian axis and maximum development of ice upon it. Deposition of the lower boulder-clay of the plains.
Gradual subsidence of the Cordilleran region and decay of the great glacier, with deposition of the boulder-clay of the interior plateau and the Yukon basin, of the lower boulder-clay of the littoral and probably also, at a later stage (and with greater submergence), of the interglacial silts of the same region.	Correlative elevation of the western part, at least, of the great plains, which was probably more or less irregular and led to the production of extensive lakes in which interglacial deposits, including peat, were formed.
Re-elevation of the Cordilleran region to a level probably as high as or somewhat higher than the present. Maximum of second period of glaciation.	Correlative subsidence of the plains, which (at least in the western part of the region) exceeded the first subsidence and extended submergence to the base of the Rocky Mountains near the forty-ninth parallel. Formation of second boulder-clay, and (at a later stage) dispersion of large erratics.

Partial subsidence of the Cordilleran region, to a level about 2,500 feet lower than the present. Long stage of stability. Glaciers of the second period considerably reduced. Upper boulder-clay of the coast probably formed at this time, though perhaps in part during the second maximum of glaciation.	Correlative elevation of the plains, or at least of their western portion, resulting in a condition of equilibrium as between the plains and the Cordillera, their *relative* levels becoming nearly as at present. Probable formation of the Missouri coteau along a shore-line during this period of rest.
Renewed elevation of the Cordilleran region, with one well-marked pause, during which the littoral stood about 200 feet lower than at present. Glaciers much reduced, and diminishing in consequence of general amelioration of climate towards the close of the Glacial period.	Simultaneous elevation of the great plains to about their present level, with final exclusion of waters in connection with the sea. Lake Agassiz formed and eventually drained towards the close of this period. This simultaneous movement in elevation of both great areas may probably have been connected with a more general northern elevation of land at the close of the Glacial period.

In New Zealand the marks of the Glacial period are unequivocal. The glaciers which now come down from the lofty mountains upon the South Island of New Zealand to within a few hundred feet of the sea then descended to the sea-level. The longest existing glacier in New Zealand is sixteen miles, but formerly one of them had a length of seventy-eight miles. One of the ancient moraines contains a boulder from thirty to forty feet in diameter, and the amount of glacial *débris* covering the mountain-sides is said to be enormous. Reports have also been recently brought of signs of ancient glaciers in Australia. — "Science", vol. xxi, p. 202. (Ap. 14, 1893),

According to Darwin, there are distinct signs of glaciation upon the plains of Patagonia sixty or seventy miles east of the foot of the mountains, and in the Straits of Ma-

gellan he found great masses of unstratified glacial material containing boulders which were at least one hundred and thirty miles away from their parent rock; while upon the

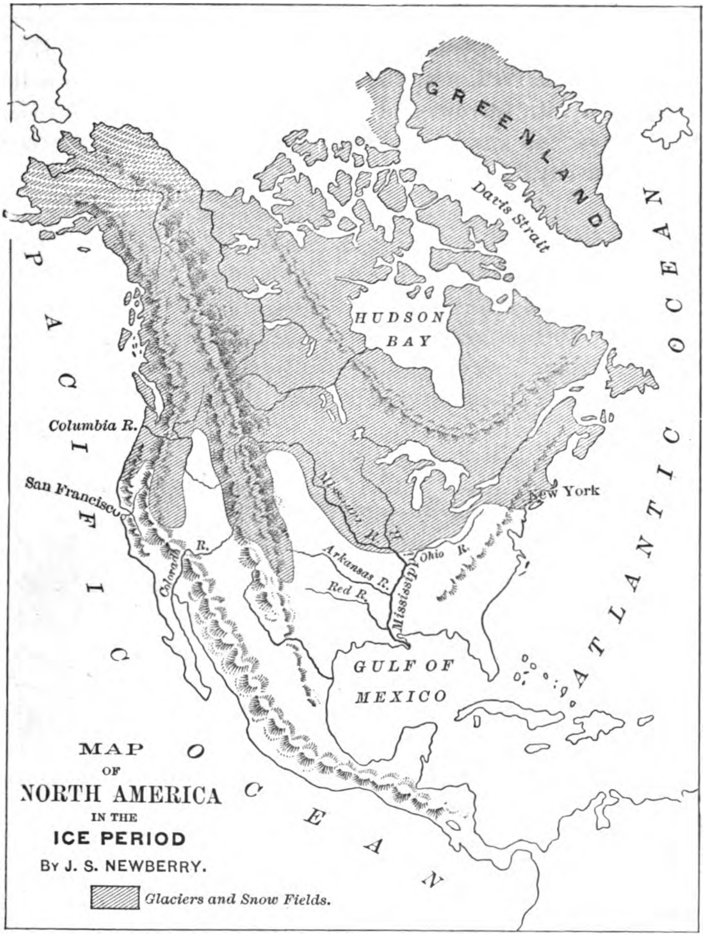

Fig. 38.—Generalised view of the whole glaciated region of North America. The area of motionless ground-ice is shown by the white lines in northern part of Alaska.

island of Chiloe he found embedded in "hardened mud" boulders which must have come from the mountain-chains of the continent. Agassiz also observed unquestionable glacial phenomena on various parts of the Fuegian coast, and indeed everywhere on the continent south of latitude 37°. Between Concepcion and Arauco, in latitude 37°, Agassiz observed, near the sea-level, a glacial surface well marked with furrows and scratches, and as well preserved, he says, "as any he had seen under the glaciers of the present day."

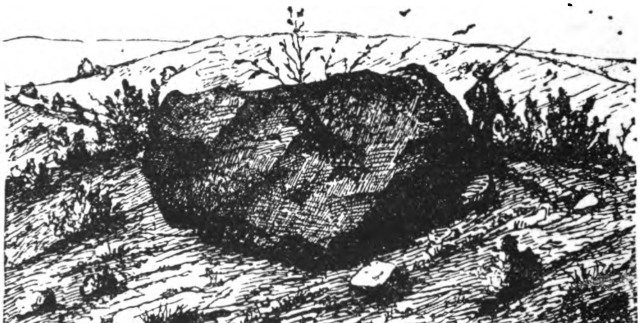

FIG. 39.—Quartzite boulder of 45 cubic metres, on Mont Lachat, 800 metres above the valley of the Belley, in Ain, France (Falsan).

CHAPTER VI.

ANCIENT GLACIERS IN THE EASTERN HEMISPHERE.

About two million square miles of northern Europe were covered with perennial ice during the Glacial period. From the scratches upon the rocks, and from the direction in which material has been transported, it is evident that the main centre of radiation is to be found in the mountains of Scandinavia, and that the glaciers still existing in Norway are the lineal descendants of those of the great Ice age.

So shallow are the Baltic Sea and the German Ocean, that their basins were easily filled with ice, upon which Scandinavian boulders could be transported westward to the east shore of England, southward into the plains of Germany, and eastward far out upon the steppes of Russia. The islands north of Scotland bear marks also of an ice-movement from the direction of Norway. If Scotland itself was not overrun with Scandinavian glaciers, the reason was that it had ice enough of its own, and from its highlands set up a counter-movement, which successfully resisted the invasion from the Scandinavian Peninsula. But, elsewhere in Europe, Scandinavian ice moved freely outward to the extent of its capacity. Then, as now also, the Alps furnished centres for ice-movement, but the glaciers were limited to the upper portions of the valleys of the Rhône, the Rhine, and the Danube upon the west and north, and to a still smaller area upon the southern side.

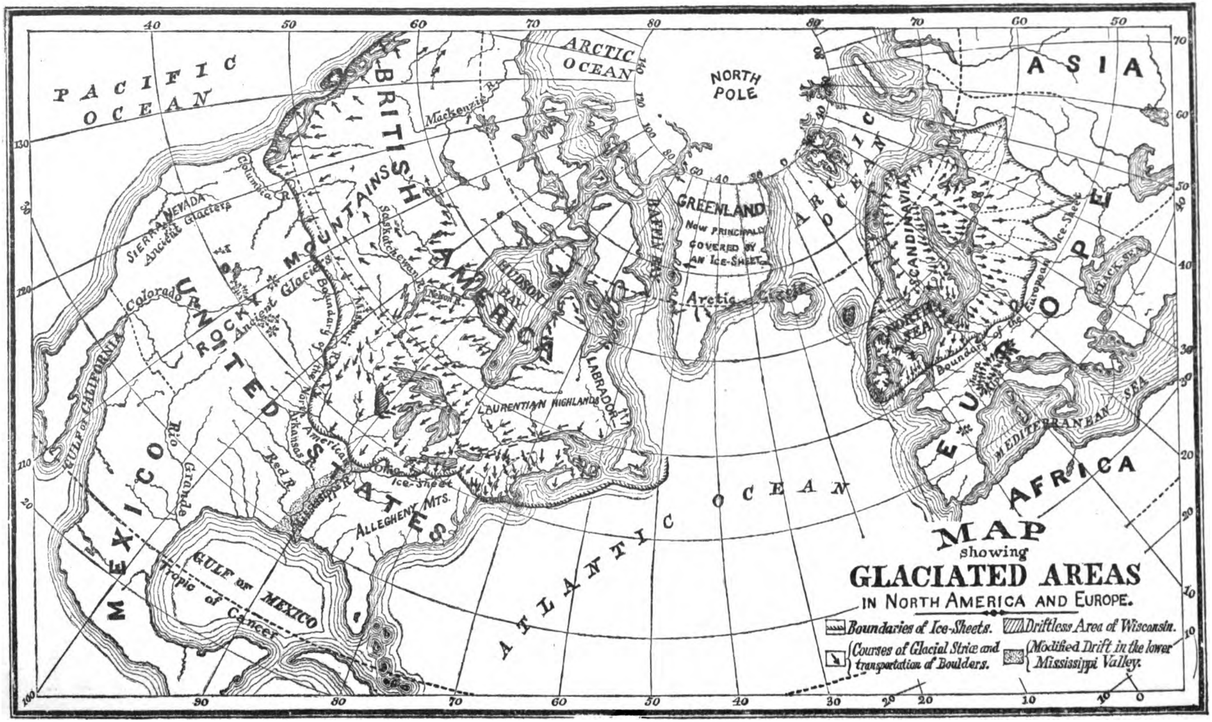
MAP
showing
GLACIATED AREAS
IN NORTH AMERICA AND EUROPE.
Boundaries of Ice-Sheets.
Driftless Area of Wisconsin.
Courses of Glacial Striæ and transportation of Boulders.
Modified Drift in the lower Mississippi Valley.
NORTH POLE
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
ARCTIC OCEAN
ASIA
EUROPE
AFRICA
BRITISH AMERICA
UNITED STATES
MEXICO
GREENLAND
NOW PRINCIPALLY COVERED BY AN ICE-SHEET
BAFFIN BAY
HUDSON BAY
LABRADOR
LAURENTIAN HIGHLANDS
ROCKY MOUNTAINS
SIERRA NEVADA
Ancient Glaciers
SCANDINAVIA
NORTH SEA
BLACK SEA
MEDITERRANEAN SEA
GULF OF MEXICO
GULF OF CALIFORNIA
Tropic of Cancer
Arctic Circle
Boundary of the European Ice-Sheet
Boundary of the North American Ice-Sheet
ALLEGHENY MTS.
Mackenzie R.
Saskatchewan R.
Nelson R.
Columbia R.
Colorado R.
Rio Grande
Red R.
Arkansas R.
Missouri R.
Mississippi R.
Ohio R.

FIG. 40.

Central and Southern Europe.

The main centres of ice-movement in the Alps during the Glacial period are the same as those which furnish the lingering glaciers of the present time. From the water-shed between the Rhine, the Rhône, and the Aar, glaciers of immense size descended all the valleys now occupied by those streams. The valley of the Rhône between the Bernese and the Pennine Alps was filled with a glacier of immense depth, which was maintained by fresh supplies from tributaries upon either side as far down as Martigny. Glacial markings at the head of the Rhône Valley are found upon the Schneestock,* at an elevation above the sea of about 11,500 feet (3,550 metres), or about 1,500 feet above the present surface of the Rhône Glacier. At Fiesch, about twenty miles below, where tributaries from the Bernese Oberland snow-fields were received, the thickness of the glacier was upwards of 5,000 feet (1,680 metres). Near Martigny, about fifty miles farther down the valley, where the glacier was abruptly deflected to the north, the depth of the ice was still upwards of 1,600 metres. From Martigny northward the thickness of the ice decreased rapidly for a few miles, where, at the enlargement of the valley above the head of Lake Geneva, it was less than 1,200 metres in thickness, and spread out over the intervening plain as far as Chasseron, with a nearly level surface, transporting, as we have before said, Alpine boulders to the flanks of the Juras, and landing them about 3,000 feet (1,275 metres) above the level of Lake Geneva. The width of the main valley is here about fifty miles, making the slope of the surface of the ice about twenty feet to the mile.

From its "vomitory," at the head of Lake Geneva, the

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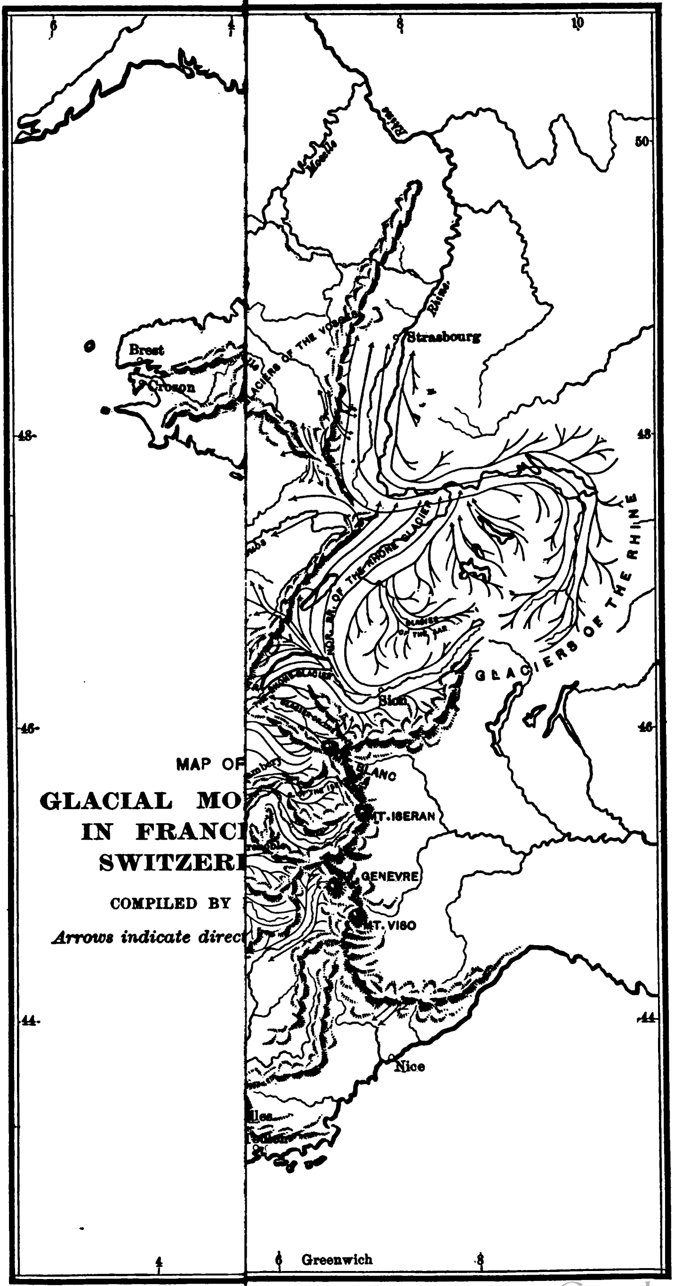
* A. Falsan's La Période Glaciaire étudiée principalement en France et en Suisse, chapitre xv.

ice of the ancient Rhône Glacier spread to the right and to the left, while its northern boundary was abruptly terminated by the line of the Jura Mountains. The law of glacial motion was, however, admirably illustrated in the height to which the ice rose upon the flanks of the Jura. At Chasseron, in the direct line of its onward motion, it rose to its highest point, while both to the southwest and to the northeast, along the line of the Juras, the ice-action was limited to constantly decreasing levels.

Down the valley of the Rhône the direction of motion was determined by the depression of Lake Geneva, at the lower end of which it received its main tributary from Mont Blanc, which had come down from Chamouni through the valley of the river Arve. From this point it was deflected by a spur of the Jura Mountains more and more southward to the vicinity of Culoz, near the mouth of Lake Bourget. Here the glacier coming down from the western flanks of the Alps, through the upper valley of the Isère, past Chambéry, became predominant, and deflected the motion to the west and north, whither the ice extended to a line passing through Bourg, Lyons, and Vienne, leaving upon one of the eminences on which Lyons is built a boulder several feet in diameter, which is duly preserved and labelled in the public park in that portion of the city. Farther south, glaciers of less extent marked the Alps most of the way to the Mediterranean, but they were not at all comparable in size to those from the central region.

To the right of Lake Geneva the movement started by the Rhône Glacier spread eastward, being joined in the vicinity of Berne by the confluent ice-stream which descended from the north flank of the Bernese Oberland, through the valley of the Aar. These united streams filled the whole valley with ice as far down as Soleure.*

* See map of Rhône Glacier, on p. 58.



MAP OF
GLACIAL MO
IN FRANC
SWITZERL
COMPILED BY
Arrows indicate direc
Brest
Crozon
Strasbourg
Moselle
Rhine
NOR. BR. OF THE RHONE GLACIER
GLACIERS OF THE RHINE
Sion
BLANC
MT. ISERAN
GENEVRE
MT. VISO
Nice
Greenwich

Farther eastward, other ice-streams from the Alps became predominant, one of which, moving down the Reuss, deployed out upon the country lying north of Lucerne and Zug. Still farther down, the ancient glacier which descended the Limmatt spread itself out over the hills and lowlands about Zurich, one of its moraines of retrocession nearly dividing the lake into two portions.

Guyot and others have shown that the superficial deposits of this portion of Switzerland are just such as would be distributed by glaciers coming down from the above-mentioned Alpine valleys. Uniting together north of Zurich, these glaciers pushed onward as far as the Rhine below Schaffhausen. In Frickthal the glacial ice was still 1,200 feet thick, and at Kaisterberg between 400 and 500 feet.

At Lucerne there is a remarkable exposure of pot-holes, and a glaciated surface such as could be produced only by the combined action of moving ice and running water; thus furnishing to tourists an instructive object-lesson. Among the remarkable instances of boulders transported a long distance in Switzerland, is that of a block of granite carried from the Valais to the vicinity of Soleure, a distance of one hundred and fifteen miles, which weighs about 4,100 tons. "The celebrated Pierre-à-Bot, above Neufchâtel, measures $50' \times 20' \times 40'$, and contains about 40,000 cubic feet of stone; while the Pierre-des-Marmettes, near Monthey, contains no less than 60,840 cubic feet."

The ancient glacier of the Rhine, receiving its initial impulse in the same centre as that of the Rhône, fully equalled it in all its dimensions. Descending eastward from its source near the Schneestock to Chur, a distance of fifty miles, it turned northward and continued forty-five miles farther to the head of Lake Constance, where it spread out in fan-shape, extending northwest to Thiengen, below Schaffhausen, and covering a considerable area north

and northeastward of the lake, reaching in the latter direction Ulm, upon the Danube—the whole distance of the movement being more than one hundred and fifty miles. Through other valleys tributary to the Danube, glaciers descended upon the upper plains of Bavaria, from the Tyrolese Alps to the vicinity of Munich. From Gross Glockner as a centre in the Noric Alps, vast rivers of ice, of which the Pasterzen Glacier is the remnant, poured far down into the valleys of the Inn and the Enns on the north and into that of the Drave on the southeast. Farther eastward in this part of Europe the mountains seem to have been too low to have furnished centres for any general dispersion of glacial ice.

Upon the south side of the Alps the ancient glaciers spread far out upon the plains of Lombardy, where moraines of vast extent and of every description enable the student to determine the exact limits of the ancient ice-action. From the southern flanks of Mont Blanc and Monte Rosa, and from the snow-fields of the western Alps, glaciers of great volume descended into the valley of Dora Baltea (vale of Aosta), and on emerging from the mountain valley spread out over the plains around Ivrea, leaving moraine hills in some instances 1,500 feet in height. The total length of this glacier was as much as

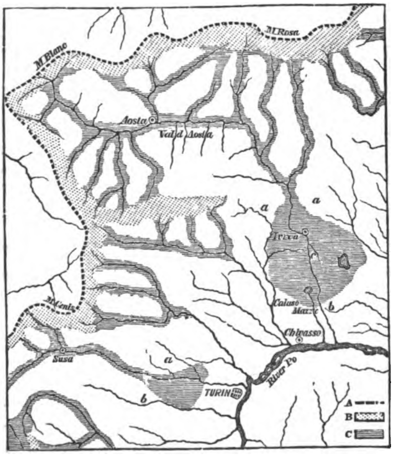


FIG. 41.—Map showing the Lines of *Débris* extending from the Alps into the Plains of the Po (after Lyell). *A*. Crest of the Alpine water-shed; *B*, Neve fields of the ancient glaciers; *C*, Moraines of ancient glaciers.

one hundred and twenty miles. From the snow-fields in the vicinity of Mont Cenis, also, glaciers extended down the Dora Ripera to the vicinity of Turin, and down other valleys to a less extent. The lateral moraines of the Diore, on the south side of Mont Blanc, at the head of the Dora Baltea, are 2,000 feet above the present river, and extend upon the left bank for a distance of twenty miles.

From the eastern Alps, glaciers descended through all the valleys of the Italian lakes and deposited vast terminal moraines, which still obstruct the drainage, and produce the charming lakes of that region. A special historic interest pertains to the series of concentric moraines south of Lake Garda, since it was in the reticulations of this glacial deposit that the last great battle for Italian liberty was fought on June 24, 1859. Defeated in the engagements farther up the valley of the Po, the Austrian general Benedek took his final stand to resist the united forces of France and Italy behind an outer semicircle of the moraine hills south of this lake (some of which are 500 or 600 feet above the surrounding country), with his centre at Solferino, about ten miles from Peschera. Here, behind this natural fortification, he awaited the enemy, who was compelled to perform his manœuvres on the open plain which spread out on every side. But the natural fortifications furnished by the moraine hills were too extensive to be defended by an army of moderate size. The troops of Napoleon and Victor Immanuel concentrated at Solferino and broke through the line. Thus the day was lost to the Austrians, and they retired from Lombardy, leaving to Italy both the artificial and the natural fortifications that guard the southern end of this important entrance to the Tyrolese Alps. When once his attention is called to the subject, the traveller upon the railroad cannot fail to notice this series of moraines, as he enters it through a tunnel at Lonato on the west, and emerges from it at Soma Campagna, eighteen or twenty miles dis-

tant to the east. A monument celebrating the victory stands upon a moraine hill about half-way between, at Martino della Battaglie.

In other portions of central and southern Europe the mountains were too low to furnish important centres for glacial movements. Still, to a limited extent, the signs of ancient glaciers are seen in the mountains of the Black Forest, in the Harz and Erzgebirge, and in the Carpathians on the east and among the Apennines on the south. In Spain, also, there were limited ice-fields on the higher portions of the Sierra Nevada and in the mountains of Estremadura, and perhaps in some other places. In France, small glaciers were to be found in the higher portions of the Auvergne, of the Morvan, of the Vosges, and of the Cevennes; while, from the Pyrenees, glaciers extended northward throughout nearly their whole extent. The ice-stream descending from the central mass of Maladetta through the upper valley of the Garonne, was joined by several tributaries, and attained a length of about forty-five miles.

The British Isles.

During the climax of the Glacial period the Hebrides to the north of Scotland were covered with ice to a depth of 1,600 feet. How far westward of this it moved out to the sea, it is of course impossible to tell. But in the channels between the Hebrides and Scotland it is evident that the water was completely expelled by the ice, and that, from a height of 1,600 feet above the Hebrides to the northern shores of Scotland, there was a continuous ice-field sloping southward at the rate of about twenty-five feet a mile.

Scotland itself was completely enveloped in glacial ice. Prevented by the Scandinavian Glacier from moving eastward, the Scotch movement was compelled to be westward and southward. On the southwest the ice-stream reached

the shores of Ireland, and became confluent with the glaciers that enveloped that island, completely filling the Irish Sea.

There are so many controverted points respecting the glacial geology of England, and they have such an important bearing upon the main question of this volume, that a pretty full discussion of them will be necessary. I have recently been over enough of the ground myself to become satisfied of the general correctness of the views entertained by my late colleague, the lamented Professor Henry Carvill Lewis, whose death in 1888 took place before the publication of his most mature conclusions. But the lines of investigation to which he gave so powerful an impulse have since been followed out by an active body of scientific observers. To give the statement of facts greater precision and authority, I have committed the preparation of it to the Secretary of the Northwest of England Boulder Committee, Percy F. Kendall, F. G. S., Lecturer on Geology at the Yorkshire College, Leeds, and at the Stockport Technical School, England.*

"All the characteristic evidences of the action of land-ice can be found in the greatest perfection in many parts of England and Wales. Drumlins, kames, *roches moutonnées*, far-travelled erratics, terminal moraines, and perched blocks, all occur. There are, besides, in the wide-spread deposits of boulder-clay which cover so many thousands of square miles on the low grounds lying on either side of the Pennine chain, evidences of the operation of ice-masses of a size far exceeding that of the grandest of existing European glaciers. But, while the proofs of protracted and severe glaciation are thus patent, there are, nevertheless, many apparently anomalous circumstances which arrest the attention when the whole country is surveyed. The glacial phenomena appear to be strictly limited to the country lying to the northward of a line ex-

* Mr. Kendall's contribution extends to page 181.

tending from the Bristol Channel to the mouth of the Thames; and within the glaciated area there are many extensive tracts of land devoid of 'drift' or other indications of ice-action.

"By comparison with the phenomena displayed in the North American continent, English glacial geology must seem puny and insignificant; but, just as with the features of the 'Solid Geology,' we have compressed within the narrow limits of our isles an epitome of the features which across the Atlantic require a continent for their exposition. It has resulted from this concentration that English geology requires a much closer and more minute investigation. And the difficulty which has been experienced by glacial geologists of dealing with an involved series of facts has, in the absence of any clue leading to the co-ordination of a vast series of more or less disconnected observations, resulted in the adoption, to meet certain local anomalies, of explanations which were very difficult if not impossible of reconciliation with facts observed in adjacent areas. Thus, to account for shell-bearing drift extending up to the water-shed on one side of a lofty range of hills, a submergence of the land to a depth of 1,400 feet has been postulated; leaving for independent explanation the fact, that the opposite slopes of the hills and the low ground beyond were absolutely destitute of drift or of any evidence of marine action.

"In the following pages I must adopt a somewhat dogmatic tone, in order to confine myself within the limits of space which are imposed; and trust rather to the cohesion and consistency of the explanations offered and to a few pregnant facts than to the weighing and contrasting of rival theories.

"The facts point conclusively to the action in the British Isles of a series of glaciers radiating outward from the great hill chains or clusters, and, as the refrigeration progressed, becoming confluent and moving though in the

same general direction, yet with less regard to the minor inequalities of the ground. During these two stages many glaciers must have debouched upon the sea-coast, with the consequent production of icebergs, which floated off with loads of boulders and dispersed them in the random fashion which is a necessary characteristic of transport by floating ice.

"With a further accentuation of the cold conditions the discharge of bergs from terminal fronts which advanced into the extremely shallow seas surrounding the British shores would be quite inadequate to relieve the great press of ice, and a further coalescence of separate elements must have resulted. In the case of enclosed seas—as, for example, the Irish Sea—the continued inthrust of glacier-ice would expel the water completely; and the conjoined ice-masses would take a direction of flow the resultant of the momentum and direction of the constituent elements. In other cases—as, for example, in the North Sea—extraneous ice approaching the shores might cause a deflection of the flow of the native glaciers, even though the foreign ice might never actually reach the shore.

"To such a system of confluent glaciers, and to the separate elements out of which they grew, and into which, after the culmination, they were resolved, I attribute the whole of the phenomena of the English and Welsh drift. And only at one or two points upon the coast, and raised but little above the sea-level, can I recognise any signs of marine action.

"*The Pre-glacial Level of the Land.*—There is very little direct evidence bearing upon this point. In Norfolk the famous forest bed, with its associated deposits, stands at almost precisely the level which it occupied in pre-glacial times. At Sewerby, near Flamborough Head, there is an ancient beach and 'buried cliff' which the sea is now denuding of its swathing of drift deposits, and its level can be seen to be almost absolutely coincident with the present

beach. Mr. Lamplugh, whose description of the 'Drifts of Flamborough Head,'* constitutes one of the gems of glacial literature, considers that there is clear evidence that the land stood at this level for a long period. The beach is covered by a rain-wash of small extent, and that in turn by an ancient deposit of blown sand, while the lowest member of the drift series of Yorkshire covers the whole. Mr. Lamplugh thinks that the blown sand may indicate a slight elevation of the land; but the beach appears to me to be the storm beach, and the reduction in the force of the waves such as would result from the approach of an ice-front a few miles to the seaward would probably produce the necessary conditions.

"Six miles to the northward of Flamborough, at Speeton, a bed of estuarine silt containing the remains of mollusca in the position of life occurs at an altitude of ninety feet above high-water mark. Mr. Lamplugh inclines to the opinion that this bed is of earlier date than the 'buried cliff'; he also admits the possibility that its superior altitude may be due to a purely local upward bulging of the soft Lower Cretaceous clays upon which the estuarine bed rests by the weight of the adjacent lofty chalk escarpment.

"The evidence obtained from inland sections and borings in different parts of England has been taken to indicate a greater altitude in preglacial times. Thus, in Essex, deep borings have revealed the existence of deep drift-filled valleys, having their floors below sea-level. The valley of the Mersey is a still better example. Numerous borings have been made in the neighbourhood of Widnes and at other places in the lower reaches of the river, making it clear that there is a channel filled with drift and extending to 146 feet below mean sea-level. This, with several other instances, has been taken to in-

* Quarterly Journal of the Geological Society, vol. xlvii.

dicate a greater altitude for the land in pre-glacial times, since a river could not erode its channel to such a depth below sea-level. The argument appears inconclusive for one principal reason: no mention is made of any river gravels or other alluvium in the borings. Indeed, there is an explicit statement that the deposits are all glacial, showing that the channel must have been cleared out by ice. This, therefore, leaves open the vital question, whether the deposits removed were marine or fluviatile. It may be remarked that the great estuary of the Mersey has undoubtedly been produced by a post-glacial (and probably post-Roman) movement of depression.

"*The Pre-Glacial Climate.*—In all speculations regarding the cause of the Glacial epoch, due account must be taken of the undoubted fact that it came on with extreme slowness and departed with comparative suddenness. In the east of England an almost perfect and uninterrupted sequence of deposits is preserved, extending from the early part of the Pliocene period down to the present day.

"These in descending order are:

"1. Post-glacial sands, gravels, etc.

"2. Glacial series.

"3. The 'Forest Bed' and associated marine deposits.

"4. Chillesford clay and sand.

"5. The many successive stages of the Red Crag. (The Norwich Crag is a local variation of the upper part of the Red Crag.)

"6. The Coralline Crag.

"The fossils preserved in these deposits, apart from the physical indications, exhibit the climatal changes which accompanied their deposition. The Coralline Crag contains a fauna consisting mainly of species which now range to the Mediterranean, many of them being restricted to the warm southern waters. Associated with these are a few boreal forms, but they are represented in general by few individuals. Here and there in the deposits of

this age far-travelled stones are to be found, but they are always accounted great rarities.

"The Red Crag consists of an irregular assemblage of beaches and sand-banks of widely different ages, but their sequence can be made out with ease by a study of the fauna. In the oldest deposits, Mediterranean species are very numerous, while the boreal forms are comparatively rare; but in successive later deposits the proportions are very gradually reversed, and from the overlying Chillesford series the Mediterranean species are practically absent. The physical indications run *pari passu* with the paleontological, and in the newer beds of the Red Crag far-travelled stones are common.

"In the Forest Bed series there is a marine band—the *Leda myalis* bed—which contains an almost arctic assemblage of shells; while at about the same horizon plant remains have been found, including such high northern species as *Salix polaris* and *Betula nana.*

"The glacial deposits do not, in my opinion, contain anywhere in England or Wales a genuine intrinsic fauna, such shells as occur in the East Anglian glacial deposits having been derived in part from a contemporary sea-bed, and, for the rest, from the older formations, down perhaps to the Coralline Crag. In the post-glacial deposits we have hardly any trace of a survival of the boreal forms, and I consider that the whole marine fauna of the North Sea was entirely obliterated at the culmination of the Glacial epoch, and that the repeopling in post-glacial times proceeded mainly from the English Channel, into which the northern forms never penetrated.

"*The Great Glacial Centres.*

"Where such complex interactions have to be described as were produced by the conflicting glaciers of the British Isles it is difficult to deal consecutively with the phenomena of any one area, but with short digressions in ex-

planation of special points it may be possible to accomplish a clear presentation of the facts.

" *Wales.*—The phenomena of South Wales are comparatively simple. Great glaciers travelled due southward from the lofty Brecknock Beacons, and left the characteristic *moutonnée* appearance upon the rocky bed over which they moved. The boulder-transport is in entire agreement with the other indications, and there are no shells in the drift. The facts awaiting explanation are the occurrence in the boulder-clays of Glamorganshire, at altitudes up to four hundred feet, of flints, and of igneous rocks somewhat resembling those of the Archæan series of the Wrekin. At Clun, in Shropshire, a train of erratics (see map) has been traced back to its source to the westward. On the west coast, in Cardigan Bay, the boulders are all such as might have been derived from the interior of Wales. At St. David's Peninsula, Pembrokeshire, striæ occur coming in from the northwest, and, taken with the discovery of boulders of northern rocks, may point to a southward extension of a great glacier produced by confluent sheets that choked the Irish Sea. Information is very scanty regarding large areas in mid-Wales, but such as can be gathered seems to point to ice-shedding having taken place from a north and south parting line. In North Wales, much admirable work has been done which clearly indicates the neighbourhood of Great Arenig (Arenig Mawr) as the radiant point for a great dispersal of blocks of volcanic rock of a characteristic Welsh type.

" *Ireland.*—A brief reference must be made to Ireland, as the ice which took origin there played an important part in bringing about some strange effects in English glaciation, which would be inexplicable without a recognition of the causes in operation across the Irish Sea. Ireland is a great basin, surrounded by an almost continuous girdle of hills. The rainfall is excessive, and the snowfall was probably more than proportionately great;

therefore we might expect that an ice-sheet of very large dimensions would result from this combination of favouring conditions. The Irish ice-sheet appears to have moved outward from about the centre of the island, but the main flow was probably concentrated through the gaps in the encircling mountains.

" *Galloway*.—The great range of granite mountains in the southwestern corner of Scotland seems to have given origin to an immense mass of ice which moved in the main to the southward, and there are good grounds for the belief that the whole ice-drainage of the area, even that which gathered on the northern side of the water-shed, ultimately found its way into the Irish Sea basin and came down coastwise and across the low grounds of the Rinns of Galloway, being pushed down by the press of Highland ice which entered the Firth of Clyde. It is a noteworthy fact that marine shells occur in the drift in the course taken by the ice coming on to the extremity of Galloway from the Clyde.

" *The Lake District*.—A radial flow of ice took place down the valleys from about the centre of the Cumbrian hill-plexus, but movement to the eastward was at first forbidden by the great rampart of the Cross Fell escarpment, which stretches like a wall along the eastern side of the Vale of Eden.

" During the time when the Cumbrian glaciers had unobstructed access to the Solway Frith, to the Irish Sea, and to Morecambe Bay, the dispersal of boulders of characteristic local rocks would follow the ordinary drainage-lines; but, as will be shown later, a state of affairs supervened in the Irish Sea which resulted, in many cases, in a complete reversal of the ice-flow.

" *The Pennine Chain* was the source of glaciers of majestic dimensions upon both its flanks in the region north of Skipton, but to the southward of that breach in the chain (see map) no evidence is obtainable of any local glaciers.

" *The Confluent Glaciers.*

" With the growth of ice-caps upon the great centres a condition of affairs was brought about in the Irish Sea productive of results which will readily be foreseen. The enormous volumes of ice poured into the shallow sea from north, south, east, and west, resulted in such a congestion as to necessitate the initiation of some new systems of drainage.

" *The Irish Sea Glacier.*—The ice from Galloway, Cumbria, and Ireland became confluent, forming what the late Professor Carvill Lewis termed 'the Irish Sea Glacier,' and took a direction to the southward. Here it came in diametrical conflict with the northward-flowing element of the Welsh sheet, which it arrested and mastered; and the Irish Sea Glacier bifurcated, probably close upon the precipitous Welsh coast to the eastward of the Little Orme's Head, and the two branches flowed coastwise to eastward and westward, keeping near the shore-line.

" The westerly branch swept round close to the coast in a southwesterly direction, and completely overrode Anglesea; striating the rock-surfaces from northeast to southwest (see map), and strewing the country with its bottom-moraine, containing characteristic northern rocks, such as the Galloway granites, the lavas and granites of the central and western portions of the Lake District, and fragments of shells derived from shell-banks in the Irish Sea. One episode of this phase of the ice-movement was the invasion of the first line of hills between the Menai Straits and Snowdon. The gravels and sands of Fridd-bryn-mawr, Moel Tryfaen, and Moel-y-Cilgwyn, are the coarser washings of the bottom-moraine, and consequently contain such rock-fragments and shells as characterise it. From Moel-y-Cilgwyn southward, evidence is lacking regarding the course taken by the glacier, but it probably passed over or between the Rivals Mountains (Yr Eifl), and down

Cardigan Bay at some distance from the coast in confluence with the ice from mid-Wales; and, as I have suggested, may have passed over St. David's Head.

"Returning now towards the head of the glacier we may follow with advantage its left bank downward. The ice-flow on the Cumberland coast appears to have resembled very much that in North Wales. A great press of ice from the northward (Galloway) seems to have had a powerful 'easting' imparted to it by the conjoint influences of the thrust of the Irish ice and the inflow of ice from the Clyde. Whatever may have been the cause, the effect is clear: about Ravenglass cleavage took place, and a flow to northward and to southward, each bending easterly. By far the larger mass took a southerly course and bent round Black Combe, over Walney, and a strip of the mainland about Barrow in Furness, and out into and across Morecambe Bay. Its limits are marked in the field by the occurrence of the same rocks which characterise it in Anglesea, viz., the granites of Galloway and of west and central Cumbria.

"The continued thrust shouldered in the glacier upon the mainland of Lancashire, but the precise point of emergence has not yet been traced, though it cannot be more than a few miles from the position indicated on the map. I should here remark, that all along the boundaries the Irish Sea Glacier was confluent with local ice, except, probably, in that part of the Pennine chain to the southward of Skipton. Down to Skipton there was a great mass of Pennine ice which was compelled to take an almost due southerly course, and thus to run directly athwart the direction of the main hills and valleys. A sharp easterly inflection of the Irish Sea Glacier carried it up the valley of the Ribble, and thence, under the shoulder of Pendle, to Burnley, where Scottish granites are found in the boulder-clay.

"On the summit of the Pennine water-shed, at Heald

Moor, near Todmorden (1,419 feet), boulder-clay has been found containing erratics belonging to this dispersion; while in the gorge of the Yorkshire Calder, which flows along the eastern side of the same hill, not a vestige of such a deposit is to be found, saving a few erratic pebbles at a distance of eight or ten miles, which were probably carried down by flood-wash from the edge of the ice.

"From this point the limits of the ice may be traced along the flanks of the Pennine chain at an average altitude of about 1,100 feet.

"At one place the erratics can be traced to a position which would indicate the formation of an extra-morainic lake having its head at a col about 1,000 feet above sea-level, separating it from the valley of an eastward flowing stream, the Wye, about twelve miles down which a few granite blocks have been found. Other extra-morainic lakes must have been formed, but very little information has been collected regarding them. The Irish Sea Glacier can be shown to have spread across the whole country to the westward of the line I have traced, and beyond the estuary of the Dee.

"I may now follow its boundaries on the Welsh coast, and pursue the line to the final melting-place of the glacier. From the Little Orme's Head the line of confluence with the native ice is pretty clearly defined. It runs in, perhaps, half a mile from the shore, until the broad low tract of the Vale of Clwyd is reached. Here the northern ice obtained a more complete mastery, and pushed in even as far as Denbigh. This extreme limit was probably attained as a mere temporary episode. Horizontal striæ on a vertical face of limestone on the crags dominating the mouth of the vale on the eastern side attest beyond dispute the action of a mass of *land-ice* moving in from the north.

"I may here remark, that in this district the deposits furnish a very complete record of the events of the Glacial

period. In the cliffs on the eastern side of the Little Orme's Head, and at several other points along the coast towards the east, a sequence may be observed as follows:

"4. Boulder-clay with northern erratics and shells.

"3. Sands and gravels with northern erratics and shells.

"2. Boulder-clay with northern erratics and shells.

"1. Boulder-clay with Welsh erratics and no shells.

"A similar succession is to be seen in the Vale of Clwyd. The interpretation is clear: In the early stages of glaciation the Welsh ice spread without hindrance to, and laid down, bed No. 1; then the northern ice came down, bringing its typical erratics and the scourings of the sea-bottom, and laid down the variable series of clays, sands, and gravels which constitute Nos. 2, 3, and 4 of the section.

"In the Vale of Clwyd an additional interest is imparted to the study of the drift from the circumstance that the remains of man have been found in deposits in caves *sealed* with drift-beds. The best example is the Cae Gwyn caves,

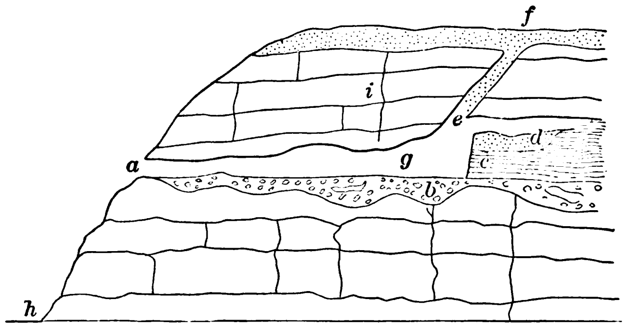


Fig. 42.—The Cefn Cave, in Vale of Clwyd. (Trimmer.) *a*, Entrance; *b*, mud with pebbles and wood covered with stalagmite; *c*, mud, bones, and angular fragments of limestone; *d*, sand and silt, with fragments of marine shells; *e*, fissure; *f*, northern drift; *g*, cave cleared of mud; *h*, river Elwy, 100 feet below; *i*, limestone rock.

in which flint implements and the bones and teeth of various extinct animals were found embedded in 'cave-

earth' which was overlaid by bedded deposits of shell-bearing drift, with erratics of the northern type.

"It has been supposed that the drift-deposits were marine accumulations; but it is inconceivable that the cave could ever have been subjected to wave-action without the complete scouring out of its contents.

"To resume the delineation of the limits of the great Irish Sea Glacier: From the Vale of Clwyd the boundary runs along the range of hills parallel to the estuary of the Dee at an altitude of about nine hundred feet. As it is traced to the southeast it gradually rises, until at Frondeg, a few miles to the northward of the embouchure of the Vale of Llangollen, it is at a height of 1,450 feet above sea-level. Thence it falls to 1,150 feet at Gloppa, three miles to the westward of Oswestry, and this is the most southerly point to which it has been definitely traced on the Welsh border, though scattered boulders of northern rocks are known to occur at Church Stretton.

"Along the line from the Vale of Clwyd to Oswestry the boundary is marked by a very striking series of moraine-mounds. They occur on the extreme summits of lofty hills in a country generally almost driftless, and their appearance is so unusual that one—Moel-y-crio—at least has been mistaken for an artificial tumulus. The limitation of the dispersal of northern erratics by these mounds is very clear and sharp; and Mackintosh, in describing those at Frondeg, remarked that, while no northern rocks extended to the westward of them, so no Welsh erratics could be found to cross the line to the eastward. There are Welsh erratics in the low grounds of Cheshire and Shropshire, but their distribution is sporadic, and will be explained in a subsequent section.

"Having thus followed around the edges of this glacier, it remains to describe its termination. It is clear that the ice must have forced its way over the low water-shed between the respective basins of the Dee and the Severn.

So soon as this ridge (less than 500 feet above the sea) is crossed, we find the deposits laid down by the glacier change their character, and sands and gravels attain a great predominance.* Near Bridgenorth, and at other places, hills composed of such materials attain an altitude of 200 feet. From Shrewsbury *via* Burton, and thence, in a semicircular sweep, through Bridgenorth and Enville, there is an immense concentration of boulders and pebbles, such as to justify the designation of a terminal moraine. To the southward, down the valley of the Severn, existing information points to the occurrence merely of such scattered pebbles as might have been carried down by floods. In the district lying outside this moraine there is a most interesting series of glacial deposits and of boulders of an entirely different character. (See map.)

"From the neighbourhood of Lichfield, through some of the suburbs of Birmingham, and over Frankley Hill and the Lickey Hills to Bromsgrove, there is a great accumulation of Welsh erratics, from the neighbourhood, probably, of Arenig Mawr.

"The late Professor Carvill Lewis suggested that these Arenig rocks might have been derived from some adjacent outcrop of Palæozoic rocks—a suggestion having its justification in the discoveries that had been made of Cumbrian rocks in the Midlands. To test the matter, an excavation was made at a point selected on Frankley Hill, and a genuine boulder-clay was found, containing erratics of the same type as those found upon the surface.

"The explanation has since been offered that this boulder-clay was a marine deposit laid down during a period of submergence.† Apart from the difficulty that the boulder-clay displays none of the ordinary characteristics of a marine deposition, but possesses a structure, or rather

* Mackintosh, Q. J. G. S.

† Proceedings of the Birmingham Philosophical Society, vol. vi, Part I, p. 181.

absence of structure, in many respects quite inconsistent with such an origin, and contains no shells or other remains of marine creatures, it must be pointed out that no theory of marine flotation will explain the distribution of the erratics, and especially their concentration in such numbers at a station sixty or seventy miles from their source.

"Upon the land-ice hypothesis this difficulty disappears. During the early stages of the Glacial period the Welsh ice had the whole of the Severn Valley at its mercy, and a great glacier was thrust down from Arenig, or some other point in central Wales, having an *initial direction*, broadly speaking, from west to east. This glacier extended across the valley of the Severn, sweeping past the Wrekin, whence it carried blocks of the very characteristic rocks to be lodged as boulders near Lichfield; and it probably formed its terminal moraine along the line indicated. (See lozenge-shaped marks on the map.) As the ice in the north gathered volume it produced the great Irish Sea Glacier, which pressed inland and down the Vale of Severn in the manner I have described, and brushed the relatively small Welsh stream out of its path, and laid down its own terminal moraine in the space between the Welsh border and the Lickey Hills. It seems probable that the Welsh stream came mainly down the Vale of Llangollen, and thence to the Lickey Hills. Boulders of Welsh rocks occur in the intervening tract by ones and twos, with occasional large clusters, the preservation of any more connected trail being rendered impossible by the great discharge of water from the front of the Irish Sea Glacier, and the distributing action of the glacier itself.

"Within the area in England and Wales covered by the Irish Sea Glacier all the phenomena point to the action of land-ice, with the inevitable concomitants of sub-glacial streams, extra-morainic lakes, etc. There is nothing to suggest marine conditions in any form except the occurrence of shells or shell fragments; and these present so

many features of association, condition, and position inconsistent with what we should be led to expect from a study of recent marine life, that conchologists are unanimous in declaring that not one single group of them is on the site whereon the shells lived. It is a most significant fact—one out of a hundred which could be cited did space permit—that in the ten thousand square miles of, as it is supposed, recently elevated sea-bottom, not a single example of a bivalve shell with its valves in apposition has ever been found! Nor has a boulder or other stone been found encrusted with those ubiquitous marine parasites, the barnacles.

"The evidences of the action of land-ice within the area are everywhere apparent in the constancy of direction of—(1.) Striæ upon rock surfaces. (2.) The terminal curvature of rocks. (3.) The 'pull-over' of soft rocks. (4.) The transportal of local boulders. (5.) The orientation of the long axes of large boulders. (6.) The false bedding of sands and gravels. (7.) The elongation of drift-hills. (8.) The relations of 'crag and tail.' There is a similar general constancy, too, in the directions of the striæ upon large boulders. Upon the under side they run longitudinally from southeast (or thereabouts) to northwest, while upon the upper surface they originate at the opposite end, showing that the scratches on the under side were produced by the stone being dragged from northwest to southeast, while those on the top were the product of the passage of stone-laden ice over it in the same direction.

"Such an agreement cannot be fortuitous, but must be attributed to the operation of some agent acting in close parallelism over the whole area. To attribute such regularity to the action of marine currents is to ignore the most elementary principles of marine hydrology. Icebergs must, in the nature of things, be the most erratic of all agents, for the direction of drift is determined—

among other varying factors—by the draught of the berg. A mass of small draught will be carried by surface currents, while one of greater depth will be brought within the influence of under-currents; and hence it not infrequently happens that while floe-ice is drifting, say, to the southeast, giant bergs will go crashing through it to the northwest. There are tidal influences also to be reckoned with, and it is matter of common knowledge that flotsam and jetsam travel back and forth, as they are alternately affected by ebb and flood tide.

"Bearing these facts in mind, it is surely too much to expect that marine ice should transport boulders (how it picked up many of them also requires explanation) with such unfailing regularity that it can be said without challenge,* 'boulders in this district [South Lancashire and Cheshire] never occur to the north or west of the parent rock.' The same rule applies without a single authentic exception to the whole area covered by the eastern branch of the Irish Sea Glacier; and hence it comes about that not a single boulder of Welsh rock has ever been recorded from Lancashire.

"*The Solway Glacier.*—The pressure which forced much of the Irish Sea ice against the Cumbrian coast-line caused, as has been described, a cleavage of the flow near Ravenglass, and, having followed the southerly branch to its termination in the midlands, the remaining moiety demands attention.

"The 'easting' motion carried it up the Solway Frith, its right flank spreading over the low plain of northern Cumberland, which it strewed with boulders of the well-known 'syenite' (granophyre) of Buttermere. When this ice reached the foot of the Cross Fell escarpment, it suffered a second bifurcation, one branch pushing to the eastward up the valley of the Irthing and over into Tyne-

* Brit. Assoc. Report, 1890, p. 343.

side, and the other turning nearly due southward and forcing its way up the broad Vale of Eden.

"Under the pressure of an enormous head of ice, this stream rose from sea-level, turned back or incorporated the native Cumbrian Glacier which stood in its path, and, having arrived almost at the water-shed between the northern and the southern drainage, it swept round to the eastward and crossed over the Pennine water-shed; not, however, by the lowest pass, which is only some 1,400 feet above sea-level, but by the higher pass of Stainmoor, at altitudes ranging from 1,800 to 2,000 feet. The lower part of the course of this ice-flow is sufficiently well characterised by boulders of the granite of the neighbourhood of Dalbeattie in Galloway; but on its way up the Vale of Eden it gathered several very remarkable rocks and posted them as way-stones to mark its course. One of these rocks, the Permian Brockram, occurs nowhere *in situ* at altitudes exceeding 700 feet, yet in the course of its short transit it was lifted about a thousand feet above its source. The Shap granite (see radiant point on map) is on the northern side of the east and west water-sheds of the Lake District, and reaches its extreme elevation, (1,656 feet) on Wasdale Pike; yet boulders of it were carried over Stainmoor, at an altitude of 1,800 feet literally by tens of thousands.

"This Stainmoor Glacier passed directly over the Pennine chain, past the mouths of several valleys, and into Teesdale, which it descended and spread out in the low grounds beyond. Pursuing its easterly course, it abutted upon the lofty Cleveland Hills and separated into two streams, one of which went straight out to sea at Hartlepool, while the other turned to the southward and flowed down the Vale of York, being augmented on its way by tributary glaciers coming down Wensleydale. The final melting seems to have taken place somewhere a little to the southward of York; but boulders of Shap granite by

which its extension is characterised have been found as far to the southward as Royston, near Barnsley.

"The other branch of the Solway Glacier—that which travelled due eastward—passed up the valley of the Irthing, and over into that of the Tyne, and out to sea at Tynemouth. It carried the Scottish granites with it, and tributary masses joined on either hand, bringing characteristic boulders with them.

"The fate of those elements of the Solway Frith Glacier which reached the sea is not left entirely to conjecture. The striated surfaces near the coast of Northumberland indicate a coastwise flow of ice from the northward—probably from the Frith of Forth—and the glaciers coming out from the Tyne and Tees were deflected to the southward.

"There is conclusive evidence that this ice rasped the cliffs of the Yorkshire coast and pressed up into some of the valleys. Where it passed the mouth of the Tees near Whitby it must have had a height of at least 800 feet, but farther down the coast it diminished in thickness. It nowhere extended inland more than a mile or two, and for the most part kept strictly to the coast-line. Along the whole coast are scattered erratics derived from Galloway and the places lying in the paths of the glaciers. In many places the cliffs exhibit signs of rough usage, the rocks being crumpled and distorted by the violent impact of the ice. At Filey Brigg a well-scratched surface has been discovered, the striation being from a few degrees east of north.

"At Speeton the evidence of ice-sheet or glacier-work is of the most striking character. On the top of the cliffs of Cretaceous strata a line of moraine-hills has been laid down, extending in wonderful perfection for a distance of six miles. They consist of a mixture of sand, gravel, and a species of clay-rubble, with occasional masses of true boulder-clay, the whole showing the arched bedding so char-

acteristic of such accumulations. At the northerly end the moraine keeps close to the edge of the chalk cliffs, which are there 400 feet high, and the hills are frequently displayed in section; but as the elevation of the cliffs declines they fall back from the edge of the cliffs and run quite across the headland of Flamborough, and are again

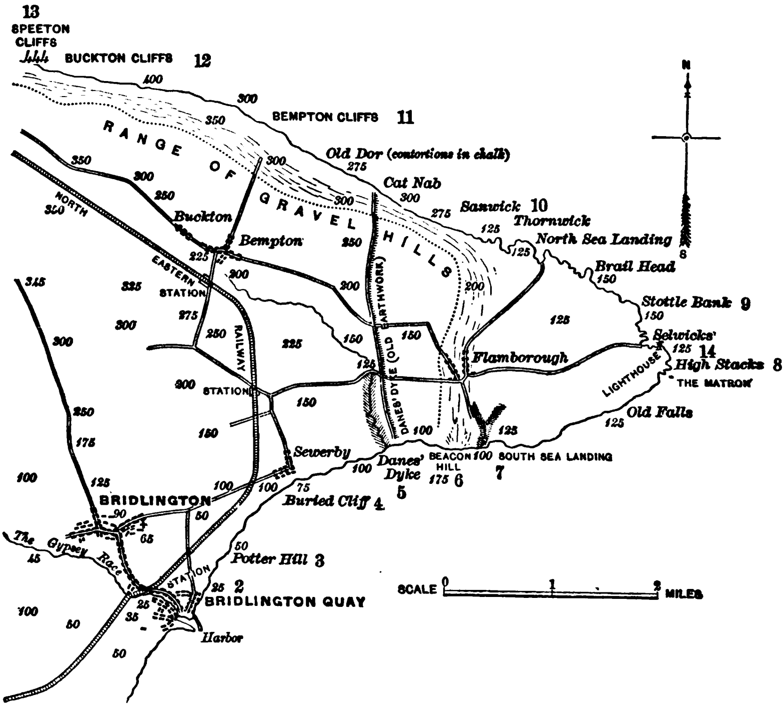


Fig. 43.—Moraine between Speeton and Flamborough (Lamplugh).

exposed in section in Bridlington Bay. One remarkable and significant fact is pointed out, namely, that behind this moraine, within half a mile and at a lower level, the country is almost absolutely devoid of any drift whatever.

"The interpretation of these phenomena is as follows:

When the valley-glaciers reached the sea they suffered the deflection which has been mentioned, partly as the result of the interference of ice from the east of Scotland, but also influenced directly by the cause which operated upon the Scottish ice and gave direction to it—that is, the impact of a great glacier from Scandinavia, which almost filled the North Sea, and turned in the eastward-flowing ice upon the British coast.

"It is easy to see how this pressure must have forced the glacier-ice against the Yorkshire coast, but vertical chalk cliffs 400 feet in height are not readily surmounted by ice of any thickness, however great, and so it coasted along and discharged its lateral moraine upon the cliff-tops. As the cliffs diminished in height we find the moraine farther inland, and, as I have pointed out, the ice completely overrode Flamborough Head. Amongst the boulders at Flamborough are many of Shap granite, a few Galloway granites, a profusion of Carboniferous rocks, brought by the Tyne branch of the Solway Glacier as well as by that of Stainmoor, and, besides many torn from the cliffs of Yorkshire, a few examples of unquestionable Scandinavian rocks, such as the well-known *Rhomben-porphyr*. It is important to note that about ten to twenty miles from the Yorkshire coast there is a tract of sea-bottom called by trawlers 'the rough ground,' in allusion to the fact that it is strewn with large boulders, amongst which are many of Shap granite. This probably represents a moraine of the Teesdale Glacier, laid down at a time when the Scandinavian Glacier was not at its greatest development.

"On the south side of Flamborough Head the 'buried cliff' previously alluded to occurs. The configuration of the country shows—and the conclusion is established by numerous deep-borings — that the pre-glacial coast-line takes a great sweep inland from here, and that the plain of Holderness is the result of the banking-up of an immense thickness of glacial *débris*. In the whole country

reviewed, from Tynemouth to Bridlington, wherever the ice came on to the land from the seaward, it brought in shells and fragmentary patches of the sea-bottom involved in its ground moraine. Space does not permit of a detailed description of the several members of the Yorkshire Drift, and I pass on to deal in a general way with the glacial phenomena of the eastern side of England.

"*The East Anglian Glacier.*—The influence of the Scandinavian ice is clearly seen in the fact that the entire ice-movement down the east coast south of Bridlington was all from the *seaward.* Clays, sands, and gravels, the products of a continuous mass of land-ice coming from the northeast are spread over the whole country, from the Trent to the high grounds on the north of London overlooking the Thames.

"The line of extreme extension of these drift-deposits runs from Finchley (near London), in the south across Hertfordshire, through Cambridgeshire, with outlying patches at Gogmagog and near Buckingham, and northwestward over a large portion of Leicestershire into the upper waters of the Trent, embracing the elevated region of Palæozoic rocks at Charnwood Forest, near Leicester.

"Reserving the consideration of the very involved questions connected with the drifts of the upper part of the Trent Valley, I may pass on to join the phenomena of the southeastern counties with those at Flamborough Head. From Nottinghamshire the limits of the drift of the East Anglian Glacier seem to run in a direction nearly due west to east, for the great oölitic escarpment upon which Lincoln Cathedral is built is absolutely driftless to the northward of the breach about Sleaford. However, along the western flank of the oölitic range true boulder-clay occurs, bordering and doubtless underlying the great fen-tract of mid-Lincolnshire; and the great Lincolnshire

Wolds appear to have been completely whelmed beneath the ice.

"The most remarkable of the deposits in this area is the Great Chalky Boulder-Clay, which consists of clay containing much ground-up chalk, and literally packed with well-striated boulders of chalk of all sizes, from minute pebbles up to blocks a foot or more in diameter. Associated with them are boulders of various foreign rocks, and many flints in a remarkably fresh condition, and still retaining the characteristic white coat, except where partially removed by glacial attrition.

"One of the perplexing features of the glacial phenomena in the eastern counties of England is the extension of true chalky boulder-clay to the north London heights at Finchley and elsewhere; for only the faintest traces are to be found in the gravel deposits of the Thames Valley of any wash from such a deposit, or from a glacier carrying such materials.

"It has been suggested that the deposit may have been laid down in an extra-morainic lake, or in an extension of the North Sea, but these suggestions leave the difficulty just where it was. If a lake or sea could exist without shores, a glacier-stream might equally dispense with banks. Within the area of glaciation, defined above, abundant evidence of the action of land-ice is obtainable, though striated surfaces are extremely rare—a fact attributable to the softness of the chalk and clays which occupy almost the whole area. Well-striated surfaces are found on the harder rocks, as, for example, on the oölitic limestone at Dunston, near Lincoln.

"Mr. Skertchly has remarked that the proofs of the action of land-ice are irrefragable. The Great Chalky Boulder-Clay covers an area of 3,000 square miles, and attains an altitude of 500 feet above the sea-level, thus bespeaking, if the product of icebergs, 'an extensive gathering-ground of chalk, having an elevation of more than

Fig. 44.—Diagram-section near Cromer (Woodward). 6. Gravel and sand (Middle Glacial) resting on contorted drift (loam, sand, and marl, with large included boulders of chalk); 5. Cromer till; 4. Laminated clay and sands (Leda-myalis bed); 3. Fresh-water loams and sands; 3*a*. Black fresh-water bed of Runton (upper fresh-water bed); 2. Forest bed—laminated clays and sands, with roots and *débris* of wood, bones of mammalia, estuarine mollusca, etc., the upper part in places penetrated by rootlets (rootlet bed); 2*a*. Weybourn crag; 1. Chalk with flints; * Large included boulder of chalk.

500 feet. But where is it? Certainly not in Western Europe, for the chalk does not attain so great an elevation except in a few isolated spots.' *

"It has been further pointed out by Mr. Skertchly, that the condition of the flints in this deposit furnishes strong evidence that they could not have been carried by floating ice nor upon a glacier, for, in either of the latter events, there must have been some exposure to the weather, which, as he remarks, would have rendered them worthless to the makers of gun-flints, whereas they are now regularly collected for their use.

"The way in which the boulder-clay is related to the rocks upon which it rests is a conclusive condemnation of any theory of floating ice; for example, where it rests upon Oxford Clay, it contains the fossils characteristic of that formation, as it is largely made up of the clay itself. The exceptions to this rule are as suggestive as those cases which conform to it. Each outcrop yields material to the boulder-clay to the southwestward, showing a pull-over from the northeast.

"One of the most remarkable features of the drift of this part of England is the inclusion of gigantic masses of rock transported for a short distance from their native outcrop, very often with so small a disturbance that they have been mapped as *in situ*. Examples of chalk-masses 800 feet in length, and of considerable breadth and thickness, have been observed in the cliffs near Cromer, in Norfolk, but they are by no means restricted to situations near the coast. One example is mentioned in which quarrying operations had been carried on for some years before any suspicion was aroused that it was merely an erratic. The huge boulders were probably dislodged from the parent rock by the thrust of a great glacier, which first crumbled the beds, then sheared off a prominent fold and

* Geikie's Great Ice Age, p. 360.

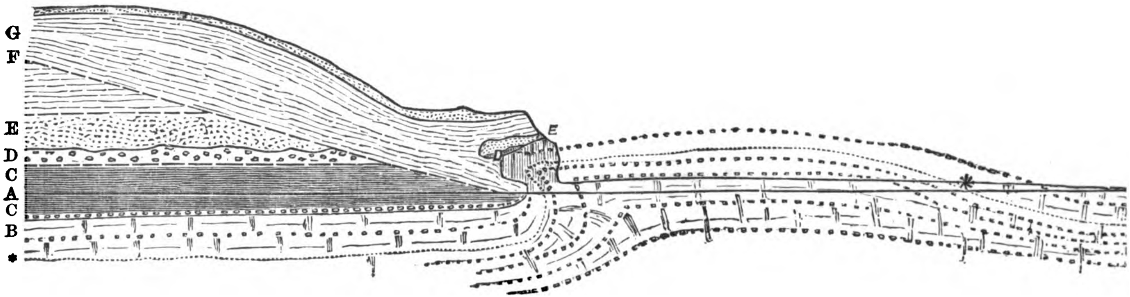


Fig. 45.—Section at right angles to the cliff through the westerly chalk bluff at Trimingham, Norfolk, showing the manner in which chalk masses are incorporated into the till (Clement Reid). Scale, 250 feet to an inch. A. Level of low-water spring-tides; B. Chalk, with sandy bed at *; C. Forest-bed series, etc., seen in the cliffs a few yards north and south of this point; D. Cromer till, stiff, lead-colored boulder-clay; E. Fine, chalky sands, much false-bedded; F. Contorted drift, brown boulder-clay with marked bedding- or fluxion-structure; G. The beds above the white line were seen and measured by Mr. Reid; * Chalk seen *in situ* on beach.

"If the ice-sheet, instead of flowing over the beds, happens to plough into them or abut against them, it would bend up a boss of chalk, as at Beeston. A more extensive disturbance, like that at Trimingham, drives before it a long ridge of the beds, and nips up the chalk, till, like a cloth creased by the sliding of a heavy book, it is folded into an inverted anticlinal. A slight increase of pressure, and the third stage is reached—the top of the anticlinal being entirely sheared off, the chalk boulder driven up an incline, and forced into the overlying boulder-clays." (Clement Reid.)

carried it along. This explanation we owe to Mr. Clement Reid.* The drift-deposits of this region frequently contain shells, but they rarely constitute what may be termed a consistent fauna, usually showing such an association as could only be found where some agent had been at work gathering together shells of different habitats and geological age.

"Attempts have been made to correlate the deposits over the whole area, but with very indifferent success. A consideration of the consequences of the invasion of the country by an ice-stream from the northeast will prepare us for any conceivable complication of the deposits.

"The main movement was against the drainage of the country, so that the ice-front must have been frequently in water. There would be aqueous deposition and erosion; the kneading up of morainic matter into ground-moraine; irregularities of distribution and deposition due to ice floating in an extra-morainic lake; flood-washes at different points of overflow; and other confusing causes, which make it rather matter for surprise that any order whatever is traceable.

"I now turn to the valley of the Trent. We find that it occupies such a position that it would be exposed, successively or simultaneously, to the action of ice-streams of most diverse origin. I have shown that the area to the westward of Lichfield was invaded at one period by a Welsh glacier, and at a subsequent one by the Irish Sea Glacier, and both of these streams entered the valley of the Trent or some of its affluents. From the eastward, again, the great North Sea Glacier encroached in like manner, carrying the Great Chalky Boulder-Clay even into the drainage area of the westward-flowing rivers near Coventry.

* See Geology of the Country around Cromer, and Geology of Holderness, Memoirs of Geological Survey of England and Wales.

"The glacial geology of the Trent Valley from Burton to Nottingham has been ably dealt with by Mr. R. M. Deeley,* who recognises a succession which may be generalised as follows: (1.) A lower series containing rocks derived from the Pennine chain; (2.) A middle series containing rocks from the eastward (chalky boulder-clay, etc.); and (3.) An upper series with Pennine rocks. Mr. Deeley thinks the Pennine *débris* may have been brought by glaciers flowing down the valleys of the Dove, the Wye, and the Derwent; but, while recognising the importance of the testimony adduced, especially that of the boulders, I am compelled to reserve judgment upon this point until something like moraines or other evidences of local glaciers can be shown in those valleys. In their upper parts there is not a sign of glaciation. Some of the deposits described must have been laid down by land-ice; while the conformation of the country shows that during some stages of glaciation a lake must have existed into which the different elements of the converging glaciers must have projected. This condition will account for the remarkable commingling of boulders observed in some of the deposits. Welsh, Cumbrian, and Scottish rocks occur in the western portion of the Trent Valley. The overflow of the extra-morainic lake would find its way into the valleys of the Avon and Severn, and may be taken to account for the abundance of flints in some of the gravels.

" *The Isle of Man.*—This little island in mid-seas constituted in the early stages of the Glacial epoch an independent centre of glaciation, and from some of its valleys ice-streams undoubtedly descended to the sea; but with the growth of the great Irish Sea Glacier the native ice was merged in the invading mass, and at the climax of the period the whole island was completely buried, even to its highest peak (Snae Fell, 2,054 feet), beneath the ice. The

* Quarterly Journal Geological Society, vol. xlii, p. 437.

effects of this general glaciation are clearly seen in the mantle of unstratified drift material which overspread the hills; in the *moutonnée* appearance of the entire island; and in the transport of boulders of local rocks. The striations upon rock surfaces show a constancy of direction in agreement with the boulder transport which can be ascribed to no other agency than a great continuous sheet of such dimensions as to ignore minor hills and valleys.

"The disposition of the striæ is equally conclusive, for we find that on a stepped escarpment of limestone both the horizontal and the vertical faces are striated continuously and obliquely from the one on to the other, showing that the ice had a power of accommodating itself to the surface over which it passed that could not be displayed by floating ice. There is a remarkable fact concerning the distribution of boulders on this island which would strike the most superficial observers, namely, that foreign rocks are confined to the low grounds. It might be argued that the local ice always retained its individuality, and so kept the foreign ice with its characteristic boulders at bay. But, apart from the *a priori* improbability of so small a hill-cluster achieving what the Lake District could not accomplish, the fact that Snae Fell, an isolated *conical* hill, is swathed in drift from top to bottom, is quite conclusive that the foreign ice must have got in. Why, then, did it carry no stones with it? The following suggestion I make not without misgivings, though there are many facts to which I might appeal that seem strongly corroborative:

"The hilly axis of the island runs in a general northeast and southwest direction, and it rises from a great expanse of drift in the north with singular abruptness, some of the hills being almost inaccessible to a direct approach without actual climbing. I imagine that the ice which bore down upon the northern end of the island

was, so far as its lower strata were concerned, unable to ascend so steep an acclivity, and was cleft, and flowed to right and left. The upper ice, being of ice-sheet origin, would be relatively clean, and this flowing straight over the top of the obstruction would glaciate the country with such material as was lying loose upon the ground or could be dislodged by mere pressure. It would appear from published descriptions that the Isle of Arran offers the same problem, and I would suggest the application of the same solution to it.

"Marine shells occur in the Manx drift, but only in such situations as were reached by the ice laden with foreign stones. They present similar features of association of shells of different habitat, and perhaps of geological age, to those already referred to as being common characteristics of the shell-faunas of the drift of the mainland. Four extinct species of mollusca have been recognised by me in the Manx drift.

"The Manx drift is of great interest as showing, perhaps better than any locality yet studied, those features of the distribution of boulders of native rocks which attest so clearly the exclusive action of land-ice. There are in the island many highly characteristic igneous rocks, and I have found that boulders of these rocks never occur to the northward of the parent mass, and very rarely in any direction except to the southwest.

"Cumming observed in regard to one rock, the Foxdale granite, that whereas the highest point at which it occurs *in situ* was 657 feet above sea-level, boulders of it occurred in profusion within 200 feet of the summit of South Barrule (1,585 feet), a hill two miles only, in a southwesterly direction, from the granite outcrop.

"They also occur on the summit of Cronk-na-Irrey-Lhaa, 1,449 feet above sea-level. The vertical uplift has been 728 and 792 feet respectively.

"In the low grounds of the north of the island a finely

developed terminal moraine extends in a great sweep so as to obstruct the drainage and convert thousands of acres of land into lake and morass, which is only now yielding to artificial drainage. Many fine examples of drumlin and esker mounds occur at low levels in different parts of the island; and it was remarked nearly fifty years ago by Cumming, that their long axes were parallel to the direction of ice-movement indicated by the striated surfaces and the transport of boulders.

"The foreign boulders are mainly from the granite mountains of Galloway, but there are many flints, presumably from Antrim, a very small number of Lake District rocks, and a remarkable rock containing the excessively rare variety of hornblende, Riebeckite. This has now been identified with a rock on Ailsa Crag, a tiny islet in the Frith of Clyde; and a Manx geologist, the Rev. S. N. Harrison, has discovered a single boulder of the highly characteristic pitchstone of Corriegills, in the Isle of Arran.

"*The So-called Great Submergence.*

"It may be convenient to adduce some additional facts which render the theory of a great submergence of the country south of the Cheviots untenable.

"The sole evidence upon which it rests is the occurrence of shells, mostly in an extremely fragmentary condition, in deposits occurring at various levels up to about 1,400 feet above sea-level. A little space may profitably be devoted to a criticism of this evidence.

"*Moel Tryfaen* ('The Hill of the Three Rocks').—This celebrated locality is on the first rise of the ground between the Menai Straits and the congeries of hills constituting 'Snowdonia'; and when we look to the northward from the top of the hill (1,350 feet) we see the ground rising from the straits in a series of gentle undulations whose smooth contours would be found from a walk across the

country to be due to the thick mask of glacial deposits which obliterates the harsher features of the solid rocks.

"The deposits on Moel Tryfaen are exposed in a slate-quarry on the northern aspect of the hill near the summit, and consist of two wedges of structureless boulder-clay, each thinning towards the top of the hill. The lower mass of clay, wherever it rests upon the rock, contains streaks and irregular patches of eccentric form, of sharp, perfectly angular fragments of slate; and the underlying rock may be seen to be crushed and broken, its cleavage-laminæ being thrust over from northwest to southeast—that is, *up-hill.* The famous 'shell-bed' is a thick series of sands and gravels interosculated with the clays on the slope of the hill, but occupying the entire section above the slate towards the top. The bedding shows unmistakable signs of the action of water, both regular stratification and false bedding being well displayed. The stones occurring in the clays are mainly if not entirely Welsh, including some from the interior of the country, and they are not infrequently of large size—two or three tons' weight—and well scratched.

"The stones found in the sands and gravels include a great majority of local rocks, but besides these there have been recorded the following:

Rock.	Source.	Highest point *in situ.*	Minimum uplift in feet.
Granite..............	Eskdale, Cumberland...	1,286	64
Granite..............	Criffel, Galloway.... ..	.....	...
Flint.................	Antrim (?).............	1,000	350
To these I can add:			
Granophyre..........	Buttermere, Cumberland	.....	...
Eurite *.............	Ailsa Craig, Frith of Clyde...............	1,097	253

* The altitude at which this rock occurs on Ailsa Craig has not been announced, so I have put it as the extreme height of the island.

"The shells in the Moel Tryfaen deposit have been fully described, so far as the enumeration of species and relative frequency are concerned, but little has been said as to their absolute abundance and their condition. The shells are extremely rare, and during a recent visit a party of five persons, in an assiduous search of about two hours, succeeded in finding *five whole shells* and about two ounces of fragments. The opportunities for collecting are as good as could be desired. The sections exposed have an aggregate length of about a quarter of a mile, with a height varying from ten to twenty feet of the shelly portion; and besides this there are immense spoil-banks, upon whose rain-washed slopes fossil-collecting can be carried on under the most favorable conditions.

"I would here remark, that the occurrence of small seams of shelly material of exceptional richness has impressed collectors with the idea that they were dealing with a veritable shell-bed, when the facts would bear a very different interpretation. A fictitious abundance is brought about by a process of what may be termed 'concentration,' by the action of a gently flowing current of water upon materials of different sizes and different specific gravities. Shells when but recently vacated consist of materials of rather high specific gravity, penetrated by pores containing animal matter, so that the density of the whole mass is far below that of rocks in general, and hence a current too feeble to move pebbles would yet carry shells. Illustrations of this process may be observed upon any shore in the concentration of fragments of coal, corks, or other light material.

"Regarding the interpretation of these facts: The commonly received idea is, that the beds were laid down in the sea during a period of submergence, and that the shells lived, not perhaps on the spot, but somewhere near, and that the terminal curvature of the slate was produced by the grounding of icebergs which also brought the boul-

ders. But if this hypothesis were accepted, it would be necessary to invest the flotation of ice with a constancy of direction entirely at variance with observed facts, for the phenomena of terminal curvature is shown with perfect persistence of direction wherever the boulder-clay rests upon the rock; and, further, there is the highly significant fact, that neither the sands and gravels nor the rock upon which they rest show any signs of disturbance or contortion, such as must have been produced if floating ice had been an operative agent.

"The uplift of foreign rocks is equally significant; and when we take into account the great distances from which they have been borne and the frequency with which such an operation must have been repeated, the inadequacy becomes apparent of Darwin's ingenious suggestion, that it might have been effected by a succession of uplifts by shore-ice during a period of slow subsidence; while the character and abundance of the molluscan remains invest with a species of irony the application of the term 'shell-bed' to the deposit.

"I now turn to the alternative explanation (see *ante*, p. 145), viz., that the whole of the phenomena were produced by a mass of land-ice which was forced in upon Moel Tryfaen from the north or northwest, overpowering any Welsh ice which obstructed its course. This view is in harmony with the observations regarding the 'terminal curvature' of the slates, the occurrence of sharp angular chips of slate in the boulder-clay, and the coincidence of direction of these indications of movement with the carry of foreign stones. The few shells and shell-crumbs in the sands and gravels would, upon this hypothesis, be the infinitesimal relics of huge shell-banks in the Irish Sea which were destroyed by the glacier and in part incorporated in its ground-moraine or involved in the ice itself. The sands and gravels would represent the wash which would take place wherever, by the occurrence of a 'nunatak' or by

approach to the edge of the ice, water could have a free escape.

"Two principal objections have been urged to the land-ice explanation of the Moel Tryfaen deposits. An able critic asks, 'Can, then, ice walk up-hill?' To this we answer, Given a sufficient 'head' behind it, and ice can certainly achieve that feat, as every *roche moutonnée* proves. If it be granted that ice on the small scale can move up-hill, there is no logical halting-place between the uplift of ten or twenty feet to surmount a *roche moutonnée*, and an equally gradual elevation to the height of Moel Tryfaen. Furthermore, the inland ice of Greenland is known to extrude its ground-moraine on the 'weather-side' of the nunataks, and the same action would account for the material uplifted on Moel Tryfaen.

"The second objection brought forward was couched in somewhat these terms: 'If the Lake District had its ice-sheet, surely Wales had one also. Could not Snowdonia protect the heart of its own domain?' Of course, Wales had its ice-sheet, and the question so pointedly raised by the objector needs an answer; and though it is merely a question of how much force is requisite to overcome a certain resistance (both factors being unknown), still there are features in the case which render it specially interesting and at the same time comparatively easy of explanation. It seems rather like stating a paradox, yet the fact is, that it was the proximity of Snowdon which, in my opinion, enabled the foreign ice to invade Wales at that point.

"A glance at the map will show that the 'radiant point' of the Welsh ice was situated on or near Arenig Mawr, and that the great mass of Snowdon stands quite on the periphery of the mountainous regions of North Wales, so that it would oppose its bulk to fend off the native ice-sheet and prevent it from extending seaward in that direction.

Scale, 1" = 8,000 Ft. Vertical; 12 Miles Horizontal.

Fig. 46.—Section across Wales to show the relations of native to foreign ice.

"As a consequence, the only Welsh ice in position to obstruct the onward march of the invader would be such trifling valley-glaciers as could form on the western slopes of Snowdon itself.

"The peak of Snowdon is 3,570 feet above sea-level, and Arenig Mawr, 2,817 feet high, is eighteen miles to the eastward, and a broad, deep valley with unobstructed access to Cardigan Bay intervenes; so, if any ice from the central mass made its way over the Snowdonian range, it performed a much more surprising feat than that involved in the ascent of Moel Tryfaen from the westward.

"The profile shows in diagrammatic form the probable relations of the foreign to the native ice at the time when the Moel Tryfaen deposits were laid down.

"From what has been said regarding the great glaciers, it would seem that ice advanced upon the land from the seaward in several parts of the coast of England, Wales, and the Isle of Man. Now, it is in precisely those parts of the country, and those alone, that the remains of marine animals occur in the glacial deposits. If the dispersal of the shells found in the drift had been effected by the means I have suggested, it would follow, as an inevitable consequence, that wherever shells occur there should also

be boulders which have been brought from beyond the sea. This I find to be the case, and in two instances the discovery of shells was preliminary to the extension of the boundaries of the known distribution of boulders of trans-marine origin.

"The officers of the Geological Survey some years ago observed the occurrence of 'obscure fragments of marine shells' in a deposit at Whalley, Lancashire, in which they could find only local rocks. One case such as this would be fatal to the theory of the *remanié* origin of the shells, but on visiting the section with Mr. W. A. Downham, I found, amongst the very few stones which occurred in the shell-bearing sand at the spot indicated, two well-marked examples of Cumbrian volcanic rocks, and, at a little distance, large boulders of Scottish granites.

"The second case is more striking. The announcement was made that shells had been found on a hill called Gloppa, near Oswestry, in Shropshire, and, as it lay about five miles to the westward of Mackintosh's boundary of the Irish Sea Glacier, and therefore well within the area of exclusively Welsh boulders, it furnished an excellent opportunity of putting the theory to the test. An examination of the boulders associated with the shells showed that the whole suite of Galloway and Cumbrian erratics such as belong to the Irish Sea Glacier were present in great abundance. Not only this, but in the midst of the series of shell-bearing gravels I observed a thin lenticular bed of greenish clay, which upon examination was found to be crowded with well-scratched specimens of Welsh rocks; but neither a morsel of shell nor a single pebble of a foreign rock could be found, either by a careful examination in the field or by washing the clay at home, and examining with a lens the sand and stones separated out.

"The fact that predictions such as these have been verified affords a very striking corroboration of the theory put forward; and, though shells cannot be found in every

deposit in which they might, *ex hypothesi*, be found, yet the strict limitation of them to situations which conform to those assigned upon theoretical grounds cannot be ascribed to mere coincidence. If the land had ever been submerged during any part of the Glacial epoch to a depth of 1,400 feet, it is inconceivable that clear and indisputable evidence should not be found in abundance in the sheltered valleys of the Lake District and Wales, which would have been deep, quiet fiords, in which vast colonies of marine creatures would have found harbour, as they do in the deep lochs of Scotland to-day.

"It has been urged, in explanation of this absence of marine remains in the great hill-centres, that the 'second glaciation' might have destroyed them; but to do this would require that the ice should make a clean and complete sweep of all the loose deposits both in the hollows of the valleys and on the hill-sides, and further that it should destroy all the shells and all the foreign stones which floated in during the submergence. At the same time we should have to suppose that the drift which lay in the paths of the great glaciers was not subjected to any interference whatever. But, assuming that these difficulties were explained, there would still remain the fact that the valleys which have never been glaciated—as, for example, those of Derbyshire—show no signs whatever of any marine deposits, nor of marine action in any form whatever.

"The sea leaves other traces also, besides shells, of its presence in districts that have really been submerged, yet there are no signs whatever to be found of them in all England, except the *post*-glacial raised beaches. Furthermore, in all the area occupied by glacial deposits there are no true sea-beaches, no cliffs nor sea-worn caves, no barnacle-encrusted rocks, nor rocks bored by Pholas or Saxicava. Are we to believe that these never existed; or that, having existed, they have been obliterated by subsequent denudations? To make good the former proposition, it would be

necessary as a preliminary to show that the movement of subsidence and re-elevation was so rapid, and the interval between so brief, that no time was allowed for any marine erosion to take place. If this were so, it would be the most stupendous catastrophe of which we have any geological record; but we are not left in doubt regarding the duration of the submerged condition, for the occurrence of forty feet of gravel upon the summits of the hills indicates plainly that, if they were accumulated by the sea, the land must have stood at that level for a very long period, amply sufficient for the formation of a well-marked coast-line.

"The alternative proposition, that post-glacial denudation had removed the traces of subsidence, is equally at variance with the evidence. Post-glacial denudation has left kames and drumlins, and all the other forms of glacial deposits, in almost perfect integrity; the small kettle-holes are not yet filled up; and it is therefore quite out of the question that the far more enduring features, such as sea-cliffs, shore platforms, and beaches, should have been destroyed.

"The only reasonable conclusion is, that these evidences of marine action never existed, because the land in glacial times was never depressed below its present level. If the level were different at all (as I think may have been the case on the western side of England), it was higher, and not lower.

"The details of the submergence hypothesis have, so far as I am aware, never been dealt with by its advocates, otherwise I cannot but think that it would have been abandoned long since. It has been stated in general terms that the subsidence was greatest in the north and diminished to zero in the south, but no attempt was made to trace the evidence of extreme subsidence across country and along the principal hill-ranges—in fact, to see how it varied in every direction.

"If we take a traverse of England, say from Flam-

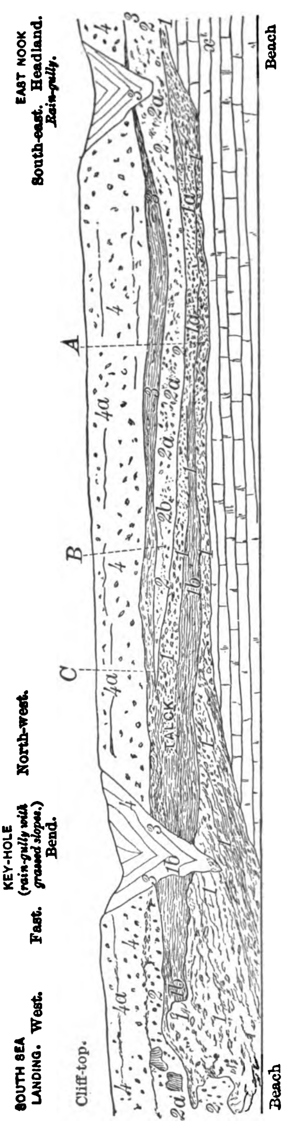


FIG. 47.—Section of the cliff on the east side of South Sea Landing, Flamborough Head. Scale, 120 feet to 1 inch; length of section, 290 yards; average height, 125 feet. (See above map of moraine between Speeton and Flamborough.)
EXPLANATION.—*4.* Brownish boulder-clay, a band of pebbles; *4a*, in places about seven feet from the top. *3.* Washed gravel, with thin sand-seams, well-bedded, pebbles chiefly erratics. *2.* "Basement" boulder-clay, with many included patches of sand, gravel, and silt; *2a*, at *B*, one of these *2b* contain shells. *1b.* Sand and silt, overlying and in places interbedded with *1.* *1.* Rubble of angular and subangular chalk-blocks and gravel, with an occasional erratic, passes partly into chalky boulder-clay, *1a.* *x.* White chalk, without flints, surface much shaken.

borough Head upon the east to Moel Tryfaen on the west, and accept as evidence of submergence any true glacial deposits (except, as in the case of the interior of Wales, the deposits are obviously the effects of purely local glaciers and contain, therefore, no shells), we shall find that the subsidence, if any, must have been not simply differential but sporadic.

"At Flamborough Head shelly drift attains an altitude of 400 feet, but half a mile from the coast the country is practically driftless even at lower levels. The Yorkshire Wolds were not submerged. On the western flanks of the wolds drift comes in at about 100 to 150 feet, and persists, probably, under the post-glacial warp, from

which it again protrudes on the western side of the valley of the Ouse, and however the drift between there and the Pennine water-shed may be interpreted, it shows not a sign of marine origin; but, even granting that it did, we find that it does not reach within a thousand feet of the water-shed. When the water-shed is crossed, however, abundant glacial deposits are met with which are not to be differentiated from others at slightly lower levels which contain shells.

"If we suppose that the line of our traverse crosses the Pennine Chain at Heald Moor, we shall find that on the eastern side no traces of drift occur above about 300 feet; while the very summit of the water-shed is occupied by boulder-clay, and thence downward the trace is practically continuous, and at about 1,000 feet and down-

FIG. 48.—Enlarged section of the shelly sand and surrounding clay at *B* in preceding figure. Scale, 4 feet to 1 inch.
EXPLANATION.—*2.* "Basement" boulder-clay. *2a.* Pure compact blue and brown clay of aqueous origin, bedding contorted and nearly obliterated, but the mass is cut up by shearing-planes. *2b.* Irregular seam, and scattered streaks, of greenish-yellow sand with many marine shells. *2c.* Patch of pale-yellow sand, different from *2b*, without trace of fossils.

ward the drift contains marine shells. Across the great plain of Lancashire and Cheshire the 'marine' drift is fully developed—though it may be remarked in parentheses that it contains a shallow-water fauna, albeit *ex hypothesi* deposited, in part at least, in a depth of 200 fathoms of water—and to the Welsh border at Frondeg, where it again reaches a water-shed at an altitude of 1,450 feet; but at 100 yards to the westward of the summit all traces of subsidence disappear, and through the centre of Wales no sign is visible; then we emerge on the western slopes at Moel Tryfaen, and they assume their fullest dimensions, though only to finish abruptly on the hill-top, and put in no appearance in the lower grounds which extend from there to the sea.

"The conclusions pointed to by the evidence (and, as I have endeavoured to show, all the evidence which existed at the close of the Glacial period is there still) are, that a subsidence of the Yorkshire Wolds took place on the east, but not in the centre or west; that the Pennine Chain was submerged on the western side to a depth of 1,400 feet, and on the east to not more than 300 feet, even on opposite sides of the same individual hill; that all the lowlands between, say, Bacup and the Welsh border, were submerged, and that the hills near Frondeg partook of this movement, but only on their eastern sides; that the centre of Wales was exempt, but that the summit of Moel Tryfaen forms an isolated spot submerged, while the surrounding country escaped. These absurdities might be indefinitely multiplied, and they must follow unless it be admitted that the phenomena are the results of glacial ice, and that ice can move 'up-hill.'

"The south of England certainly has partaken of no movement of subsidence. A line drawn from Bristol to London will leave all the true glacial deposits to the northward, except a bed of very questionable boulder-clay at Watchet, and a peculiar deposit of clayey rubble which

has been produced on the flanks of the Cornish hills probably, as the late S. V. Wood, Jr, suggested, by the slipping of material over a permanently frozen subsoil.

"For the remainder of the southern area the evidence is plain that there has been no considerable subsidence during glacial times. The presence over large areas of chalk country of the 'clay with flints'—a deposit produced by the gradual solution of the chalk and the accumulation *in situ* of its insoluble residue—is absolute demonstration that for immense periods of time the country has been exempt from any considerable aqueous action. The enormous accumulations of china clay upon the granite bosses of Cornwall and Devon tell the same tale. A few erratics have been found at low levels at various points on the southern coasts, usually not above the reach of the waves. These consist of rocks which may have been floated by shore-ice from the Channel Islands or the French coast.

"This imperfect survey of the evidence against the supposed submergence has been rendered the more difficult by the fact that it is not considered necessary to produce the evidence of marine shells in all cases. Indeed, it has been argued that post-Tertiary beds covering thousands of square miles might be absolutely destitute of shells without prejudice to the theory of their formation in the sea.

"But such a suggestion, one would think, could hardly come from any one familiar with marine Tertiary deposits, or even with the appearance of modern sea-beaches. Admitting, however, for the purposes of argument, that the beaches along a great extent of coast might be devoid of shells, it cannot be argued that the deep waters were destitute of life; and hence the boulder-clays, if of marine origin, should contain a great abundance of shells and other remains, and, once entombed, it is beyond belief that they could all be removed from such a deposit in the short lapse of post-glacial time.

"Now, some of the boulder-clays—as, for example, those

of Lancashire and Cheshire—are held to be of marine origin, and this is indeed a vital necessity to the submergence theory; for, if these are not marine deposits, neither are the other shelly deposits; but these boulder-clays are absolutely indistinguishable from those lying within the hill-centres, and, as it passes belief that such deposits could be of diverse origin and yet possess an identical structure and arrangement, then we should have a right to demand that these clays should have enclosed shells and should still contain them, but they do not.

"I may here mention that I am informed by Mr. W. Shone, F. G. S.—and he was good enough to permit me to quote the statement—that the boulder-clay of Cheshire and the shelly boulder-clay of Caithness are 'as like as two peas.' The importance of this comparison lies in the fact that, since Croll's classical description, all observers have agreed that it was the product of land-ice which moved in upon the land out of the Dornoch Firth. It was pointed out then, as since has been done for England, that it was only where the direction of ice-movement was from the seaward that any shells occur in the boulder-clay.

"*The Dispersion of Erratics of Shap Granite.*—So great a significance attaches to the peculiar distribution of this remarkable rock, that I may add a few details here which could not be conveniently introduced elsewhere.

"This granite occupies an area which lies just to the northward of the water-shed between the basins of the Lime and the Eden, and its extreme elevation is 1,656 feet. Boulders occur in large numbers as far to the northward as Cross Fells, while, as already described, they pass over Stainmoor and are dispersed in great numbers along the route taken by the great Stainmoor branch of the Solway Glacier. But a considerable number of the boulders also found their way to the southward, and a well-marked trail can be followed down into Morecambe Bay; and at Hest Bank, to the north of Lancaster, the boulder-clay

contains many examples, together with the 'mica-trap' of the Kendal and Sedbergh dykes and other local rocks, but no shells or erratics from other sources than the country draining into Morecambe Bay. To the southward the ice which bore these rocks was deflected by the great Irish Sea Glacier, and, so far as present information enables me to state, the Shap granite blocks mark the course of the medial moraine between these two ice-streams. It has been found near Garstang, at Longridge, and at Whalley, this being the exact line of junction of the Irish Sea Glacier with the ice from Morecambe Bay and the Pennine Chain.

"It is a very remarkable and significant fact, that not a single authentic occurrence of the rock across the boundary indicated has yet been recorded."

Northern Europe.

On passing over the shallow German Sea from England to the Continent, the southern border of the Scandinavian ice-field is found south of the Zuyder Zee, between Utrecht and Arnhem—the moraine hills in the vicinity of Arnhem being quite marked, and a barren, sandy plain dotted with boulders and irregular moraine hills extending most of the way to the Zuyder Zee. From Arnhem the southern boundary of the great ice-field runs "eastward across the Rhine Valley, along the base of the Westphalian Hills, around the projecting promontory of the Hartz, and then southward through Saxony to the roots of the Erzgebirge. Passing next southeastward along the flanks of the Riesen and Sudeten chain, it sweeps across Poland into Russia, circling round by Kiev, and northward by Nijni-Novgorod towards the Urals." * Thence the boundary passes northward to the Arctic Ocean, a little east of the White Sea.

* A. Geikie's Text-Book of Geology, p. 885.

The depth of this northern ice-sheet is proved to have been upwards of 1,400 feet where it met the Hartz Mountains, for it has deposited northern *débris* upon them to that height; while, as already shown, it must have been over 2,000 feet in the main valley of Switzerland. In Norway it is estimated that the ice was between 6,000 and 7,000 feet thick.

The amount of work done by the continental glaciers of Europe in the erosion, transportation, and deposition of rock and earthy material is immense. According to Helland, the average depth of the glacial deposits over North Germany and northwestern Russia is 150 German feet, i. e., about 135 English feet. As the deposition towards the margin of a glacier must be commensurate with its erosion near the centre of movement, this vast amount implies a still greater proportionate waste in the mountains of Scandinavia, where the area diminishes with every contraction of the circle. Two hundred and fifty feet is therefore not an extravagant calculation for the amount of glacial erosion in the Scandinavian Peninsula.

It is not difficult to see how the Scandinavian mountains were able to contribute so much soil to the plains of northern Germany and northwestern Russia. Previous to the Glacial period, a warm climate extended so far north as to permit the growth of semi-tropical vegetation in Spitzbergen, Greenland, and the northern shores of British America. Such a climate, with its abundant moisture and vegetation, afforded most favourable conditions for the superficial disintegration of the rocks. When, therefore, the cold of the Glacial period came on, the moving currents of ice would have a comparatively easy task in stripping the mantle of soil from the hills of Norway and Sweden, and transporting it towards the periphery of its movement. Of course, erosion in Scandinavia meant subglacial deposition beyond the Baltic. Doubtless, therefore, the plains of northern Germany, with their great

depth of soil, are true glacial deposits, whose inequalities of surface have since been much obliterated, through the general influences of the lapse of time, and by the ceaseless activity of man.

An interesting series of moraines in the north of Germany, bordering the Baltic Sea, was discovered in 1888 by Professor Salisbury, of the United States Geological Survey. Its course lies through Schleswig-Holstein, Mecklenburg, Potsdam (about forty miles north of Berlin), thence swinging more to the north, and following nearly the line between Pomerania and West Prussia, crossing the Vistula about twenty miles south of Dantzic, thence easterly to the Spirding See, near the boundary of Poland.

Among the places where this moraine can be best seen are—"1. In Province Holstein, the region about (especially north of) Eutin; 2. Province Mecklenburg, north of Crivitz, and between Bütow and Kröpelin; 3. Province Brandenburg, south of Reckatel, between Strassen and Bärenbusch, south of Fürstenberg and north of Everswalde, and between Pyritz and Solden; 4. Province Posen, east of Locknitz, and at numerous points to the south, and especially about Falkenburg, and between Lompelburg and Bärwalde. This is one of the best localities. 5. Province West Preussen, east of Bütow; 6. Province Ost Preussen, between Horn and Widikin."

Comparing these with the moraines of America, Professor Salisbury remarks:

"In its composition from several members, in its variety of development, in its topographic relations, in its topography, in its constitution, in its associated deposits, and in its wide separation from the outermost drift limit, this morainic belt corresponds to the extensive morainic belt of America, which extends from Dakota to the Atlantic Ocean. That the one formation corresponds to the other does not admit of doubt. In all essential characteristics

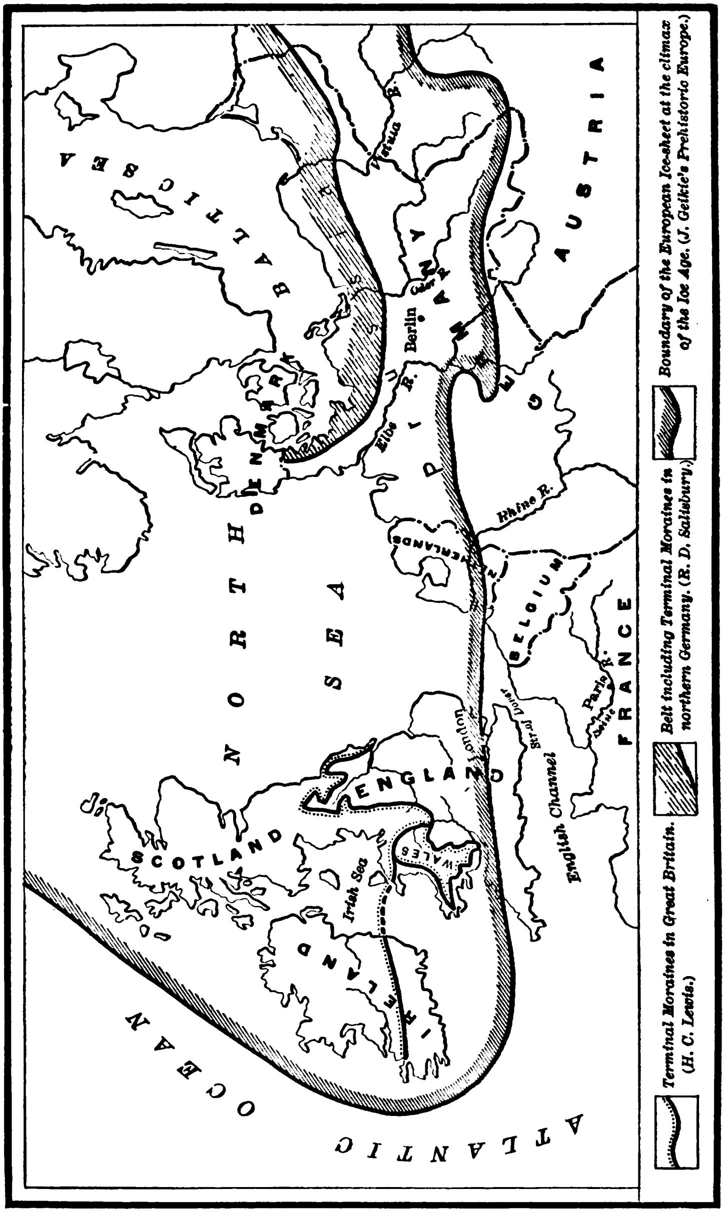


Fig. 49.—Map showing the glaciated area of Enrope according to J. Geikie, and the moraines in Britain and Germany according to Lewis and Salisbury.

they are identical in character. What may be their relations in time remains to be determined."

The physical geography of Europe is so different from that of America, that there was a marked difference in the secondary or incidental effects of the Glacial period upon the two regions. In America the continental area over which the glaciers spread is comparatively simple in its outlines. East of the Rocky Mountains, as we have seen, the drainage of the Glacial period was, for a time, nearly all concentrated in the Mississippi basin, and the streams had a free course southward.

But in Europe there was no free drainage to the south, except over a small portion of the glaciated area in central Russia, about the head-waters of the Dnieper, the Don, and the Volga; though the Danube and the Rhône afforded free course for the waters of a portion of the great Alpine glaciers. But all the great rivers of northern Europe flow to the northward, and, with the exception of the Seine, they all for a time encountered the front of the continental ice-sheet. This circumstance makes it difficult to distinguish closely between the direct glacial deposits in Europe and those which are more or less modified by water action. At first sight it would seem also somewhat hazardous to attempt to correlate with any portion of the Glacial period the deposition of the gravelly and loamy deposits in valleys, which, like those of the Seine and Somme, lie entirely outside of the glaciated area.

Upon close examination, however, the elements of doubt more and more disappear. The Glacial period was one of great precipitation, and it is natural to suppose that the area of excessive snow-fall extended considerably beyond the limit of the ice-front. During that period, therefore, the rivers of central France must have been annually flooded to an extent far beyond anything which is known at the present time. Since these rivers flowed to

the northward, at a period when, during the long and severe winters, the annual accumulation of ice near their mouths was excessive, ice-gorges of immense extent, such as now form about the mouths of the Siberian rivers, would regularly occur. We are not surprised, therefore, to find, even in these streams, abundant indications of the indirect influence of the great northern ice-sheet.

The indications referred to consist of high-level gravel terraces occasionally containing boulders, of from four to five tons weight, which have been transported for a considerable distance. The elevation of the terraces above the present flood-plains of the Seine and Somme reaches from 100 to 150 feet. We are not to suppose, however, that even in glacial times the floods of the river Seine could have filled its present valley to that height. The highest flood in this river known in historic times rose only to a height of twenty-nine feet. Mr. Prestwich estimates that, without taking into consideration the more rapid discharge, a flood of sixty times this magnitude would be required to fill the present valley to the level of the ancient gravels, while at Amiens the shape of the valley of the Somme is such that five hundred times the mean average of the stream would be required to reach the high-level gravels. The conclusion, therefore, is that the troughs of these streams have been largely formed by erosion since the deposition of the high-level gravels.

Connected with these terrace gravels in northern France is a loamy deposit, corresponding to the loess in other parts of Europe, and to a similar deposit to which we have referred in describing the southwestern part of the glaciated area in North America. In northern France this fine silt overlies the high-level gravel deposits, and, as Mr. Prestwich has pretty clearly shown, was deposited contemporaneously with them during the early inundations and before the stream had eroded its channel to its present level.

The distribution of loess in Europe was doubtless connected with the peculiar glacial conditions of the continent. Its typical development is in the valley of the Rhine, where it is described by Professor James Geikie "as a yellow or pale greyish-brown, fine-grained, and more or less homogeneous, consistent, non-plastic loam, consisting of an intimate admixture of clay and carbonate of lime. It is frequently minutely perforated by long, vertical, root-like tubes which are lined with carbonate of lime—a structure which imparts to the loess a strong tendency to cleave or divide in vertical planes. Thus it usually presents upright bluffs or cliffs upon the margins of streams and rivers which intersect it. Very often it contains concretions or nodules of irregular form. . . . Land-shells and the remains of land animals are the most common fossils of the loess, but occasionally fresh-water shells and the bones of fresh-water fish occur."

"From the margins of the modern alluvial flats which form the bottoms of the valleys it rises to a height of 200 or 300 feet above the streams—sweeping up the slopes of the valleys, and imparting a rich productiveness to many districts which would otherwise be comparatively unfruitful. From the Rhienthal itself it extends into all the tributary valleys—those of the Neckar, the Main, the Lahn, the Moselle, and the Meuse, being more or less abundantly charged with it. It spreads, in short, like a great winding-sheet over the country—lying thickly in the valleys and dying off upon the higher slopes and plateaux. Wide and deep accumulations appear likewise in the Rhône Valley, as also in several other river-valleys of France, as in those of the Seine, the Saône, and the Garonne, and the same is the case with many of the valleys of middle Germany, such as those of the Fulda, the Werra, the Weser, and the upper reaches of the great basin of the Elbe. It must not be supposed that the loess is restricted to valleys and depressions in the surface of the ground.

"It is true that it attains in these its greatest thickness, but extensive accumulations may often be followed far into the imtermediate hilly districts and over the neighbouring plateaux. Thus the Odenwald, the Taunus, the Vogelgebirge, and other upland tracts, are cloaked with loess up to a considerable height. Crossing into the drainage system of the Danube, we find that this large river and many of its tributaries flow through vast tracts of loess. Lower Bavaria is thickly coated with it, and it attains a great development in Bohemia, Upper and Lower Austria, and Moravia—in the latter country rising to an elevation of 1,300 feet. It is equally abundant in Hungary, Galicia, Bukowina, and Transylvania. From the Danubian flat lands and the low grounds of Galicia it stretches into the valleys of the Carpathians, up to heights of 800 and 2,000 feet. In some cases it goes even higher—namely, to 3,000 feet, according to Zeuschner, and to 4,000 or 5,000 feet, according to Korzistka. These last great elevations, it will be understood, are in the upper valleys of the northern Carpathians. In Roumania loess is likewise plentiful, but it has not been observed south of the Balkans. East of the Carpathians—that is to say, in the regions watered by the Dniester, the Dnieper, and the Don—loess appears also to be wanting, and to be represented by those great steppe-deposits which are known as *Tchernozen*, or black earth." *

The shells found in the loess indicate both a colder and a wetter climate during its deposition than that which now exists. The relics of land animals are infrequently found in the deposit, yet they do occur, but mostly in fragmentary condition—the principal animals represented being the mammoth, the rhinoceros, the reindeer, and the horse; which is about the same variety as is found in the gravel

* Prehistoric Europe, pp. 144–146.

deposits of the Glacial period, both in western Europe and in America.

A species of loess—differing, however, somewhat in color from that on the Rhine—covers the plains of north-eastern France up to an elevation of 700 feet above the the sea, where, as we have already said, it overlies the high-level gravels of the Seine and the Somme. Above this height the superficial soil in France is evidently merely the decomposed upper surface of the native rock.

The probable explanation of all these deposits, included under the term "loess," is the same as that already given by Prestwich of the loamy deposits of northern France. But in case of rivers, which, like the Rhine, encountered the ice-front in their northward flow, a flooded condition favouring the accumulation of loess was doubtless promoted by the continental ice-barrier. In the case of the Danube and the Rhône, however, where there was a free outlet away from the glaciated region, the loess in the upper part of the valleys must have accumulated in connection with glacial floods quite similar to those which we have described as spreading over the imperfectly formed water-courses of the Mississippi basin during the close of the Ice age. That the typical loess is of glacial origin is pretty certainly shown, both by its distribution in front of glaciers and by its evident mechanical origin when studied under the microscope. It is, in short, the fine sediment which gives the milky whiteness to glacial rivers.

In central Russia there is a considerable area in which the glacial conditions were, in one respect, similar to those in the northern part of the Mississippi Valley in the United States. In both regions the continental ice-sheet surmounted the river partings, and spread over the upper portion of an extensive plain whose drainage was to the south. The Dnieper, the Don, and the western branch of the Volga, like the Ohio and the Mississippi, have their head-waters in the glaciated region. In some other respects,

also, there is a resemblance between the plains bordering the glaciated region in central Russia and those which in America border it in the Mississippi Valley. Mr. James Geikie is of the opinion that the extensive belt of black earth adjoining the glaciated area in Russia, and constituting the most productive agricultural portion of the country, derives its fertility, as does much of the Mississippi Valley, from the blanket of glacial silt spread pretty evenly over it. Thus it would appear that in Europe, as in America, the ice of the Glacial period was a most beneficent agent, preparing the face of the earth for the permanent occupation of man. On both continents the seat of empire is in the area once occupied by the advance of the great ice-movements of that desolate epoch.

Asia.

East of the Urals, in northern Asia, there is no evidence of moving ice upon the land during the Glacial period; but at Yakutsk, in latitude 62° north, the soil is frozen at the present time to an unknown depth, and many of the Siberian rivers, as they approach and empty into the Arctic Sea, flow between cliffs of perpetual ice or frozen ground. The changes that came over this region during the Glacial period are impressively indicated by the animal remains which have been preserved in these motionless icy cliffs. In the early part of the period herds of mammoth and woolly rhinoceros roamed over the plains of Siberia, and waged an unequal warfare with the slowly converging and destructive forces. The heads and tusks of these animals were so abundant in Siberia that they long supplied all Russia with ivory, besides contributing no small amount for export to other countries. "In 1872 and 1873 as many as 2,770 mammoth-tusks, weighing from 140 to 160 pounds each, were entered at the London docks."* So

* Prestwich's Geology, vol. ii, p. 460.

perfectly have the carcasses of these extinct animals been preserved in the frozen soil of northern Siberia that when, after the lapse of thousands of years, floods have washed them out from the frozen cliffs, dogs and wolves and bears have fed upon their flesh with avidity. In some instances even "portions of the food of these animals were found in the cavities of the teeth. Microscopic examination showed that they fed upon the leaves and shoots of the coniferous trees which then clothed the plains of Siberia." A skeleton and parts of the skin, and some of the softer portions of the body of a mammoth, discovered in 1799 in the frozen cliff near the mouth of the Lena, was carried to St. Petersburg in 1806, from which it was ascertained that this huge animal was "covered with a light-coloured, curly, very thick-set hair one to two inches in length, interspersed with darker-colored hair and bristles from four to eighteen inches long." *

In the valleys of Sikkim and eastern Nepaul, in northern India, glaciers formerly extended 6,000 feet lower than now, or to about the 5,000-foot level, and in the western Himalayas to a still lower level. The higher ranges of mountains in other portions of Asia also show many signs of former glaciation. This is specially true of the Caucasus, where the ancient glaciers were of vast extent. According, also, to Sir Joseph Hooker, the cedars of Lebanon flourish upon an ancient moraine. Of the glacial phenomena in other portions of Asia little is known.

Africa.

Northern and even central Africa must likewise come in for their share of attention. The Atlas Mountains, rising to a height of 13,000 feet, though supporting none at the present time, formerly sustained glaciers of considerable size. Moraines are found in several places as low as

* Prestwich's Geology, vol. ii, p. 460.

the 4,000-foot level, and one at an altitude of 4,000 feet is from 800 to 900 feet high, and completely crosses and dams up the ravine down which the glacier formerly came.

Some have supposed that there are indubitable evidences of former glaciation in the mountain-ranges of southwestern Africa between latitude 30° and 33°, but the evidence is not as unequivocal as we could wish, and we will not pause upon it.

The mountains of *Australia*, also, some of which rise to a height of more than 7,000 feet, are supposed to have been once covered with glacial ice down to the level of 5,800 feet, but the evidence is at present too scanty to build upon. But in *New Zealand* the glaciers now clustering about the peaks in the middle of the South Island, culminating in Mount Cook, are but diminutive representatives of their predecessors. This is indicated by extensive moraines in the lower part of the valleys and by the existence of numerous lakes, attributable, like so many in Europe and North America, to the irregular deposition of morainic material by the ancient ice-sheet.*

* See With Axe and Rope in the New Zealand Alps, by G. E. Mannering, 1891.

CHAPTER VII.

DRAINAGE SYSTEMS AND THE GLACIAL PERIOD.

WE will begin the consideration of this part of our subject, also, with the presentation of the salient facts in North America, since that field is simpler than any field in the Old World.

The natural drainage basins of North America east of the Rocky Mountains are readily described. The Mississippi River and its branches drain nearly all the region lying between the Appalachian chain and the Rocky Mountains and south of the Dominion of Canada and of the Great Lakes. All the southern tributaries to the Great Lakes are insignificant, the river partings on the south being reached in a very short distance. The drainage of the rather limited basin of the Great Lakes is northeastward through the St. Lawrence River, leaving nearly all of the Dominion of Canada east of the Rocky Mountains to pour its surplus waters northward into Hudson Bay and the Arctic Ocean. With the exception of the St. Lawrence River, these are essentially permanent systems of drainage. To understand the extent to which the ice of the Glacial period modified these systems, we must first get before our minds a picture of the country before the accumulation of ice began.

Preglacial Erosion.

Reference has already been made to the elevated condition of the northern and central parts of North Amer-

ica at the beginning of the Glacial period. The direct proof of this preglacial elevation is largely derived from the fiords and great lake basins of the continent. The word "fiord" is descriptive of the deep and narrow inlets of the sea specially characteristic of the coasts of Norway, Denmark, Iceland, and British Columbia. Usually also fiords are connected with valleys extending still farther inland, and occupied by streams.

Fiords are probably due in great part to river erosion when the shores stood at considerably higher level than now. Slowly, during the course of ages, the streams wore out for themselves immense gorges, and were assisted, perhaps, to some extent by the glaciers which naturally came into existence during the higher continental elevation. The present condition of fiords, occupied as they usually are by great depths of sea-water, would be accounted for by recent subsidence of the land. In short, fiords seem essentially to be submerged river gorges, partially silted up near their mouths, or perhaps partially closed by terminal moraines.

It is not alone in northwestern Europe and British Columbia that fiords are found, but they characterize as well the eastern coast of America north of Maine, while even farther south, both on the Atlantic and on the Pacific coast, some extensive examples exist, whose course has been revealed only to the sounding-line of the Government survey.

The most remarkable of the submerged fiords in the middle Atlantic region of the United States is the continuation of the trough of Hudson River beyond New York Bay. As long ago as 1844 the work of the United States Coast Survey showed that there was a submarine continuation of this valley, extending through the comparatively shallow waters eighty miles or more seaward from Sandy Hook.

The more accurate surveys conducted from 1880 to

1884 have brought to our knowledge the facts about this submarine valley almost as clearly as those relating to the

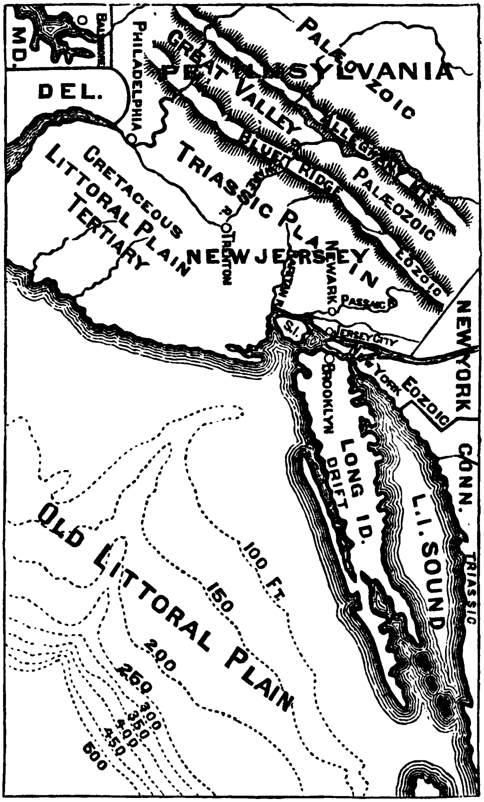


FIG. 50.—Map showing old channel and mouth of the Hudson (Newberry).

inland portion of it above New York city. According to Mr. A. Lindenkohl,* this submarine valley began to be noticeable in the soundings ten miles southeast of Sandy Hook. The depth of the water where the channel begins is nineteen fathoms (114 feet). Ten miles out the chan-

* Bulletin of the Geological Society of America, vol. i, p. 564; American Journal of Science, June, 1891.

nel has sunk ninety feet below the general depth of the water on the bank, and continues at this depth for twenty miles farther. This narrow channel continues with more or less variation for a distance of seventy-five miles, where it suddenly enlarges to a width of three miles and to a depth of 200 fathoms, or 1,200 feet, and extends for a distance of twenty-five miles, reaching near that point a depth of 474 fathoms, or 2,844 feet. According to Mr. Lindenkohl, this ravine maintains for half its length "a vertical depth of more than 2,000 feet, measuring from the top of its banks, and the banks have a nearly uniform slope of about 14°. The mouth of the ravine opens out into the deep basin of the central Atlantic.

With little question there is brought to light in these remarkable investigations a channel eroded by the extension of the Hudson River, into the bordering shelf of the Atlantic basin at a time when the elevation of the continent was much greater than now. This is shown to have occurred in late Tertiary or post-Tertiary times by the fact that the strata through which it is worn are the continuation of the Tertiary deposits of New Jersey. The subsidence to its present level has probably been gradual, and, according to Professor Cook, is still continuing at the rate of two feet a century.

Similar submarine channels are found extending out from the present shore-line to the margin of the narrow shelf bordering the deep water of the central Atlantic running from the mouth of the St. Lawrence River, through St. Lawrence Bay, and through Delaware and Chesapeake Bays.* All these submerged fiords on the Atlantic coast were probably formed during a continental elevation which commenced late in the Tertiary period, and reached the amount of from 2,000 to 3,000 feet in the northern part of the continent.

* See Lindenkohl in American Journal of Science, for June, 1891.

To this period must probably be referred also the formation of the gorge, or more properly fiord, of the

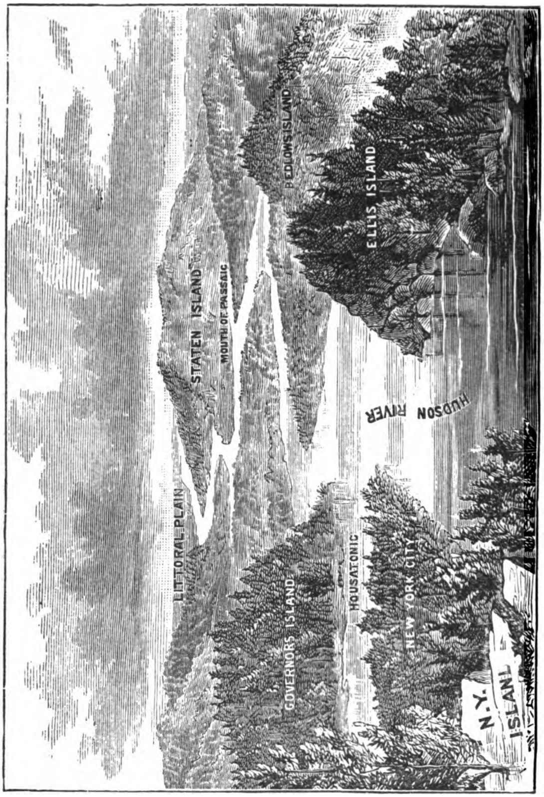


FIG. 51.—New York harbor in preglacial times, looking south, from south end of New York Island (Newberry).

Saguenay, which joins the St. Lawrence below Quebec. The great depth of this fiord is certainly surprising, since, according to Sir William Dawson, its bottom, for fifty miles above the St. Lawrence, is 840 feet below the sea-level, while the bordering cliffs are in some places 1,500 feet above the water. The average width is something over a mile.

It seems impossible to account for such a deep gorge extending so far below the sea-level, except upon the supposition of a long-continued continental elevation, which should allow the stream to form a cañon to an extent somewhat comparable with that of the cañons of the Colorado and other rivers in the far West. Then, upon the subsidence of the continent to the present level, it would remain partially or wholly submerged, as we find it at the present time. During the Glacial period it was so filled with ice as to prevent silting up. The rivers entering the Pacific Ocean, both in the United States and in British Columbia, are also lost in submerged channels extending out to the deeper waters of the Pacific basin in a manner closely similar to the Atlantic streams which have been mentioned.

During this continental elevation which preceded, accompanied, and perhaps brought on the Glacial period, erosion must have proceeded with great intensity along all the lines of drainage, and throughout the whole region which is now covered, and to a considerable extent smoothed over, by glacial deposits, and the whole country must have presented a very different appearance from what it does now.

A pretty definite idea of its preglacial condition can probably be formed by studying the appearance of the regions outside of and adjoining that which was covered by the continental glacier. The contrast between the glaciated and the unglaciated region is striking in several respects aside from the presence and absence of transported rocks and other *débris*, but in nothing is it greater than in the extent of river erosion which is apparent upon the surface. For example, upon the western flanks of the Alleghanies the regions south of the glacial limit is everywhere deeply channeled by streams. Indeed, so long have they evidently been permitted to work in their present channels that, wherever there have been waterfalls, they

have receded to the very head-waters, and no cataracts exist in them at the present time. Nor are there in the unglaciated region any lakes of importance, such as characterize the glaciated region. If there have been lakes, the lapse of time has been sufficient for their outlets to lower their beds sufficiently to drain the basins dry.

On entering the glaciated area all this is changed. The ice-movement has everywhere done much to wear down the hills and fill the valleys, and, where there was *débris* enough at command, it has obliterated the narrow gorges originally occupied by the preglacial streams. Thus it has completely changed the minor lines of superficial drainage, and in many instances has produced most extensive and radical changes in the whole drainage system of the region. In the glaciated area, channels buried beneath glaciated *débris* are of frequent occurrence, while many of the streams which occupy their preglacial channels are flowing at a very much higher level than formerly, the lower part of the channel having been silted up by the superabundant *débris* accessible since the glacial movement began.

Buried Outlets and Channels.

It is easy to see how the great number of shallow lakes which frequent the glaciated region were formed by the irregular deposition of glacial *débris*, but it is somewhat more difficult to trace out the connection between the Glacial period and the Great Lakes of North America, several of which are of such depth that their bottoms are some hundreds of feet below the sea-level, Lake Erie furnishing the only exception. This lake is so shallow that it is easy to see how its basin may have been principally formed by river erosion, while it is evident that such must have been the mode of its formation, since it is surrounded by sedimentary strata lying nearly in a horizontal position.

That Lake Erie is really nothing but a "glacial mill-pond" is proved also by much direct evidence, especially that derived from the depth of the buried channels of the streams flowing into it from the south. Of these, the Cuyahoga River, which enters the lake at Cleveland, has been most fully investigated. In searching for oil, some years ago, borings were made at many places for twenty-five miles above the mouth of the river. As a result, it appeared that for the whole distance the rocky bottom of the gorge was about two hundred feet below the present bottom of the river, while the river itself is two or three hundred feet below the general level of the country, occupying a trough about half a mile in width, with steep, rocky sides. These facts indicate that at one time the

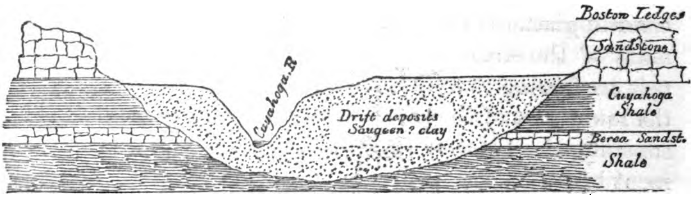


FIG. 52.—Section across the valley of the Cuyahoga River, twenty miles above its mouth (Claypole).

river must have found opportunity to discharge its contents at a level two hundred feet below that of the present lake, while an examination of the material filling up the bottom of the gorge to its present level shows it to be glacial *débris*, thus proving that the silting up was accomplished during the Glacial period.

As the water of Lake Erie is for the most part less than one hundred feet in depth, and is nowhere much more than two hundred feet deep, it is clear that the preglacial outlet which drained it down to the level of the rocky bottom of the Cuyahoga River must have destroyed the lake altogether. Hence we may be certain that, before the Glacial period, the area now covered by the lake was

simply a broad, shallow valley through which there coursed a single river of great magnitude, with tributary branches occupying deep gorges. Professor J. W. Spencer has shown with great probability that the old line of drainage from Lake Erie passed through the lower part of the valley of Grand River, in Canada, and entered Lake Ontario at its western extremity, and that during the great Ice age this became so completely obstructed with glacial *débris* as to form an impenetrable dam, and to cause the pent-up water to flow through the Niagara Valley, which chanced to furnish the lowest opening.

In speaking of the present area of Lake Erie, however, as being then occupied by a river valley, we do not mean to imply that it was not afterwards greatly modified by glacial erosion; for undoubtedly this was the case, whatever views we may have as to the relative efficiency of ice and water in scooping out lake basins.

In the case of Lake Erie, we need suppose no change of level to account for the erosion of its basin, but only that, since the strata in which it is situated were deposited, time enough had elapsed for a great river to cut a gorge extending from the western end of Lake Ontario through to the present bed of Lake Erie, and that here a great enlargement of the valley was occasioned by the existence of deep beds of soft shale which could easily be worn away by a ramifying system of tributary streams. Rivers acting at present relative levels would be amply sufficient to produce the results which are here manifest.

But in the case of Lakes Ontario, Huron, Michigan, and Superior, whose depths descend considerably below the sea-level, we must suppose that they were, in the main, eroded when the continent was so much elevated that their bottoms were brought above tide-level. The depth of Lake Ontario implies the existence of an outlet more than four hundred feet lower than at present, which, of course, could exist only when the general ele-

vation was more than four hundred feet greater than now.

The existence of an outlet at that depth seems to be proved also by the fact that at Syracuse, where numerous wells have been sunk to obtain brine for the manufacture of salt, deposits of sand, gravel, and rolled stones, four hundred and fifty feet thick, are penetrated without reaching rock. Since this lies in the basin of Lake Ontario, it follows that if the basin itself has been produced by river erosion, the land must have been of sufficient height to permit an outlet through a valley, or cañon, of the required depth, and this outlet must now be buried beneath the abundant glacial *débris* that covers the region.

Professor Newberry, who has studied the vicinity carefully, is of the opinion that there is ample opportunity for such a line of drainage to have extended through the Mohawk Valley to the Hudson River. But, at Little Falls, a spur of the Adirondack Mountains projects into the valley, and the Archæan rocks over which the river runs are so prominent and continuous that some have thought it impossible for the requisite channel to have ever existed there. Extensive deposits of glacial *débris*, however, are found in the vicinity, especially in places some distance to the north, and in Professor Newberry's opinion the existence of a buried channel around the obstruction upon the north side is by no means improbable.

The preglacial drainage of Lake Huron has not been determined with any great degree of probability. Professor Spencer formerly supposed that it passed from the southern end of the lake through London, in the western part of Ontario, and reached the Erie basin near Port Stanley, and so augmented the volume of the ancient river which eroded the buried cañon from Lake Erie to Lake Ontario. But he now supposes, though the evidence is by no means demonstrative, that the waters of Lake Huron passed into Lake Ontario by means of a channel

extending from Georgian Bay to the vicinity of Toronto.

With a fair degree of probability, the basin of Lake Superior is supposed by Professor Newberry to have been joined to that of Lake Michigan by some passage, now buried, considerably to the west of the Strait of Mackinac, and thence to have had an outlet southward from the vicinity of Chicago directly into the Mississippi River. Of this there is considerable evidence furnished by deeply buried channels which have been penetrated by borings in various places in Kankakee, Livingston, and McLean Counties, Illinois; but the whole area extending from Lake Michigan to the Mississippi is so deeply covered with glacial *débris* that the surface of the country gives no satisfactory indication of the exact lines of preglacial drainage.

Some of the most remarkable instances of ancient river channels buried by the glacial deposits have been brought to light in southwestern Ohio, where there has been great activity in boring for gas and oil. At St. Paris, Champaign County, for example, in a locality where the surface of the rock near by was known to be not far below the general level, a boring was begun and continued to a depth of more than five hundred feet without reaching rock, or passing out of glacial *débris*.

Many years ago Professor Newberry collected sufficient facts to show that pretty generally the ancient bed of the Ohio River was as much as 150 feet below that over which it now flows. During a continental elevation the erosion had proceeded to that extent, and then the channel had been silted up during the Glacial period with the abundant material carried down by the streams from the glaciated area. One of the evidences of the preglacial depth of the channel of the Ohio was brought to light at Cincinnati, where "gravel and sand have been found to extend to a depth of over one hundred feet below

low-water mark, and the bottom of the trough has not been reached." In the valley of Mill Creek, also, "in the suburbs of Cincinnati, gravel and sand were penetrated to the depth of 120 feet below the stream before reaching rock." But from the general appearance of the channel, Professor J. F. James was led to surmise that a rock bottom extended all the way across the present channel of the Ohio, between Price Hill and Ludlow, Ky., a short distance below Cincinnati, which would preclude the possibility of a preglacial outlet at the depth disclosed in that direction. Mr. Charles J. Bates (who was inspector of the masonry for the Cincinnati Southern Railroad while building the bridge across the Ohio at this point) informs me that Mr. James's surmise is certainly correct, and that his "in all probability" may be displaced by "certainly," since the bedded rocks supposed by Professor James to extend across the river a few feet below its present bottom were found by the engineers to be in actual existence.

In looking for an outlet for the waters of the upper Ohio which should permit them to flow off at the low level reached in the channel at Cincinnati, Professor James was led to inspect the valley extending up Mill Creek to the north towards Hamilton, where it joins the Great Miami. The importance of Mill Creek Valley is readily seen in the fact that the canal and the railroads have been able to avoid heavy grades by following it from Cincinnati to Hamilton. As a glance at a map will show, it is also practically but a continuation of the northerly course pursued by the Ohio for twenty miles before reaching Cincinnati. This, therefore, was a natural place in which to look beneath the extensive glacial *débris* for the buried channel of the ancient Ohio, and here in all probability it has been found. The borings which have been made in Milk Creek Valley north of Cincinnati, show that the bedded rock lies certainly thirty-four feet below the low-water mark of the Ohio just below Cincinnati, while

at Hamilton, twenty-five miles north of Cincinnati, where the valley of the Great Miami is reached, the bedded rock of the valley lies as much as ninety feet below present low-water mark in the Ohio.

Other indications of the greater depth of the preglacial gorge of the Ohio are abundant. "At the junction of the Anderson with the Ohio, in Indiana, a well was sunk ninety-four feet below the level of the Ohio before rock was found." At Louisville, Ky., the occurrence of falls in the Ohio seemed at first to discredit the theory in question, but Professor Newberry was able to show that the falls at Louisville are produced by the water's being now compelled to flow over a rocky point projecting from the north side into the old valley, while to the south there is ample opportunity for an old channel to have passed around this point underneath the city on the south side. The lowlands upon which the city stands are made lands, where glacial *débris* has filled up the old channel of the Ohio.

Above Cincinnati the tributaries of the Ohio exhibit the same phenomena. At New Philadelphia, Tuscarawas County, the borings for salt-wells show that the Tuscarawas is running 175 feet above its ancient bed. The Beaver, at the junction of the Mahoning and Chenango, is flowing 150 feet above the bottom of its old trough, as is demonstrated by a large number of oil-wells bored in the vicinity. Oil Creek is shown by the same proofs to run from 75 to 100 feet above its old channel, and that channel had sometimes vertical and even overhanging walls.*

The course of preglacial drainage in the upper basin of the Alleghany River is worthy of more particular mention. Mr. Carll, of the Pennsylvania Geological Survey, has adduced plausible reasons for believing that previous

* Geological Survey of Ohio, vol. ii, pp. 13, 14.

to the Glacial period the drainage of the valley of the upper Alleghany north of the neighbourhood of Tidioute, in Warren County, instead of passing southward as now, was collected into one great stream flowing northward through the region of Cassadaga Lake to enter the Lake Erie basin at Dunkirk, N. Y. The evidence is that between Tidioute and Warren the present Alleghany is shallow, and flows over a rocky basin; but from Warren northward along the valley of the Conewango, the bottom of the old trough lies at a considerably lower level, and slopes to the north. Borings show that in thirteen miles the slope of the preglacial floor of Conewango Creek to the north is 136 feet. The actual height above tide of the old valley floor at Fentonville, where the Conewango crosses the New York line, is only 964 feet; while that of the ancient rocky floor of the Alleghany at Great Bend, a few miles south of Warren, was 1,170 feet. Again, going nearer the head-waters of the Alleghany, in the neighbourhood of Salamanca, it is found that the ancient floor of the Alleghany is, at Carrollton, 70 feet lower than the ancient bed of the present stream at Great Bend, about sixty miles to the south; while at Cole's Spring, in the neighbourhood of Steamburg, Cattaraugus County, N. Y., there has been an accumulation of 315 feet of drift in a preglacial valley whose rocky floor is 155 feet below the ancient rocky floor at Great Bend. Unless there has been a great change in levels, there must, therefore, have been some other outlet than the present for the waters collecting in the drainage basin to the north of Great Bend.*

While there are numerous superficial indications of buried channels running towards Lake Erie in this region,

* For a criticism of Mr. Carll's views, see an article on Pleistocene Fluvial Planes of Western Pennsylvania, by Mr. Frank Leverett, in American Journal of Science, vol. xlii, pp. 200–212.

direct exploration has not been made to confirm these theoretical conclusions. In the opinion of Mr. Carll, Chautauqua Lake did not flow directly to the north, but, passing through a channel nearly coincident with that now occupied by it, joined the northerly flowing stream a few miles northeast from Jamestown.* It is probable, however, that Chautauqua did not then exist as a lake, since the length of preglacial time would have permitted its outlet to wear a continuous channel of great depth corresponding to that known to have existed in the Conewango and upper Alleghany.

The foregoing are but a few of the innumerable instances where the local lines of drainage have been disturbed, and even permanently changed, by the glacial deposits. Almost every lake in the glaciated region is a witness to this disturbance of the established lines of drainage by glacial action, while in numerous places where lakes do not now exist they have been so recently drained that their shore-lines are readily discernible.

An interesting instance of the recent disappearance of one of these glacial lakes is that of Runaway Pond, in northern Vermont. In the early part of the century the Lamoille River had its source in a small lake in Craftsbury, Orleans County. The sources of the Missisquoi River were upon the same level just to the north, and the owner of a mill privilege upon this latter stream, desiring to increase his power by obtaining access to the water of the lake, began digging a ditch to turn it into the Missisquoi, but no sooner had he loosened the thin rim of compact material which formed the bottom and the sides of the inclosure, than the water began to rush out through the underlying and adjacent quicksands. This almost instantly enlarged the channel, and drained the whole body of water off in an incredibly short time. As a consequence,

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* Second Geological Survey of Pennsylvania, vol. iii.

the torrent went rushing down through the narrow valley, sweeping everything before it; and nothing but the unsettled condition of the country prevented a disaster like that which occurred in 1889 at Johnstown, Pa. Doubtless there are many other lakes held in position by equally slender natural embankments. Artificial reservoirs are by no means the only sources of such danger.

The buried channel of the old Mississippi River in the vicinity of Minneapolis is another instructive example of the instability of many of the present lines of drainage. The gorge of the Mississippi River extending from Fort Snelling to the Falls of St. Anthony at Minneapolis is of post-glacial origin. One evidence of this is its narrowness when contrasted with the breadth of the valley below Fort Snelling. Below this point the main trough of the Mississippi has a width of from two to eight miles, and the faces of the bluffs on either side show the marks of extreme age. The tributary streams also have had time to wear gorges proportionate to that of the main stream, and the agencies which oxidise and discolor the rocks have had time to produce their full effects. But from Fort Snelling up to Minneapolis, a distance of about seven miles, the gorge is scarcely a quarter of a mile in width, and the faces of the high, steep bluffs on either side are remarkably fresh looking by comparison with those below; while the tributary gorges, of which that of the Minnehaha River is a fair specimen, are very limited in their extent.

Upon looking for the cause of this condition of things we observe that the broad trough of the Mississippi River, which had characterised it all the way below Fort Snelling, continues westward, without interruption, up the valley of the present Minnesota River, and, what seems at first most singular, it does not cease at the sources of the Minnesota, but, through Lake Traverse and Big Stone

Lake, is continuous with the trough of the Red River of the North.

Deferring, however, for a little the explanation of this,

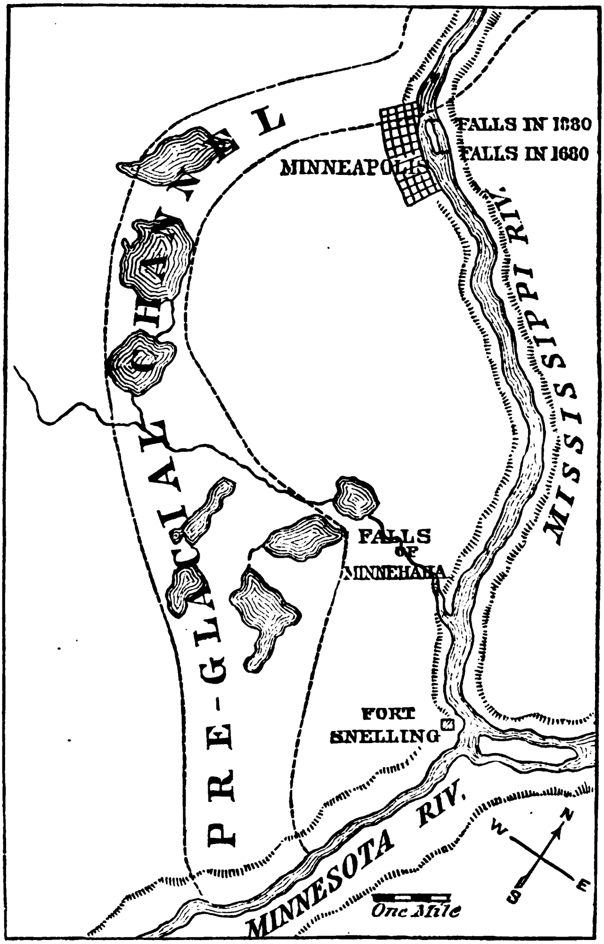

Fig. 53.—Map of Mississippi River from Fort Snelling to Minneapolis and the vicinity, showing the extent of the recession of the Falls of St. Anthony since the great Ice age. Notice the greater breadth of the valley of the Minnesota River as described in the text (Winchell).

we will go back to finish the history of the preglacial channel around the Falls of St. Anthony. As early as the year 1876 Professor N. H. Winchell had collected sufficient evidence from wells, one of which had been sunk to a depth of one hundred and seventy-five feet, to show that the preglacial course of the stream corresponding to the present Mississippi River ran to the west of Minneapolis and of the Falls of Minnehaha, and joined the main valley some distance above Fort Snelling, as shown in the accompanying map.

This condition of things was at one time very painfully brought to the notice of the citizens of Minneapolis. A large part of the wealth of the city at that time consisted of the commercial value of the water-power furnished by the Falls of St. Anthony. To facilitate the discharge of the waste water from their wheels, some mill-owners dug a tunnel through the soft sandstone underlying the limestone strata over which the river falls; but it very soon became apparent that the erosion was proceeding with such rapidity that in a few years the recession of the falls would be carried back to the preglacial channel, when the river would soon scour out the channel and destroy their present source of wealth. The citizens rallied to protect their property, and spent altogether as much as half a million dollars in filling up the holes that had been thoughtlessly made; but so serious was the task that they were finally compelled to appeal for aid to the United States Government. Permanent protection was provided by running a tunnel, some ways back from the falls, completely across the channel, through the soft sandstone underlying the limestone, and filling this up with cement hard enough and compact enough to prevent the further percolation of the water from above.

Ice-Dams.

The foregoing changes in lines of drainage due to the Glacial period were produced by deposits of earthy material in preglacial channels. Another class of temporary but equally interesting changes were produced by the ice itself acting directly as a barrier.

Many such lakes on a small scale are still in existence in various parts of the world. The Merjelen See in Switzerland is a well-known instance. This is a small body of water held back by the great Aletsch Glacier, in a little valley leading to that of the Fiesch Glacier, behind the Eggischorn. At irregular intervals the ice-barrier gives way, and allows the water to rush out in a torrent and flood the valley below. Afterwards the ice closes up again, and the water reaccumulates in preparation for another flood.

Other instances in the Alps are found in the Mattmark See, which fills the portion of the Saas Valley between Monte Rosa and the Rhône. This body of water is held in place by the Allalin Glacier, which here crosses the main valley. The Lac du Combal is held back by the Glacier de Miage at the southern base of Mont Blanc. "A more famous case is that of the Gietroz Glacier in the valley of Bagnes, south of Martigny. In 1818 this lake had grown to be a mile long, and was 700 feet wide and 200 feet deep. An attempt was made to drain it by cutting through the ice, and about half the water was slowly drawn off in this way; but then the barrier broke, and the rest of the lake was emptied in half an hour, causing a dreadful flood in the valley below. In the Tyrol, the Vernagt Glacier has many times caused disastrous floods by its inability to hold up the lake formed behind it. In the northwestern Himalaya, the upper branches of the Indus are sometimes held back in this way. A noted flood occurred in 1835; it advanced twenty-five miles in

an hour, and was felt three hundred miles down-stream, destroying all the villages on the lower plain, and strewing the fields with stones, sand, and mud.*

In Greenland such temporary obstructions are frequent, forming lakes of considerable size. Instances occur, in connection with the Jakobshavn and the Frederickshaab Glaciers, and in the North Isortok and Alangordlia Fiords.

Frequently, also, bodies of water of considerable size are found in depressions of the ice itself, even at high levels. I have myself seen them covering more than an acre, and as much as a thousand feet above the sea-level, upon the surface of the Muir Glacier, Alaska. They are reported by Mr. I. C. Russell † of larger size and at still higher elevations upon the glaciers radiating from Mount St. Elias; while the explorers of Greenland mention them of impressive size upon the surface of its continental ice-sheet.

With these facts in mind we can the more readily enter into the description which will now be given of some temporary lakes of vast size which were formed by direct ice-obstructions during portions of the Glacial period.

One of the most interesting of these is illustrated upon the accompanying map, which will need but little description.

While tracing the boundary-line of the glaciated area in the Mississippi Valley during the summer of 1882, I discovered the existence of unmistakable glacial deposits in Boone County, Kentucky, across the Ohio River, from Cincinnati. These deposits were upon the height of land 550 feet above the Ohio River, or nearly 1,000 feet above

* Professor William M. Davis in Proceedings of the Boston Society of Natural History, vol. xxi, pp. 350, 351.

† See National Geographic Magazine, vol. iii, pp. 116–120.

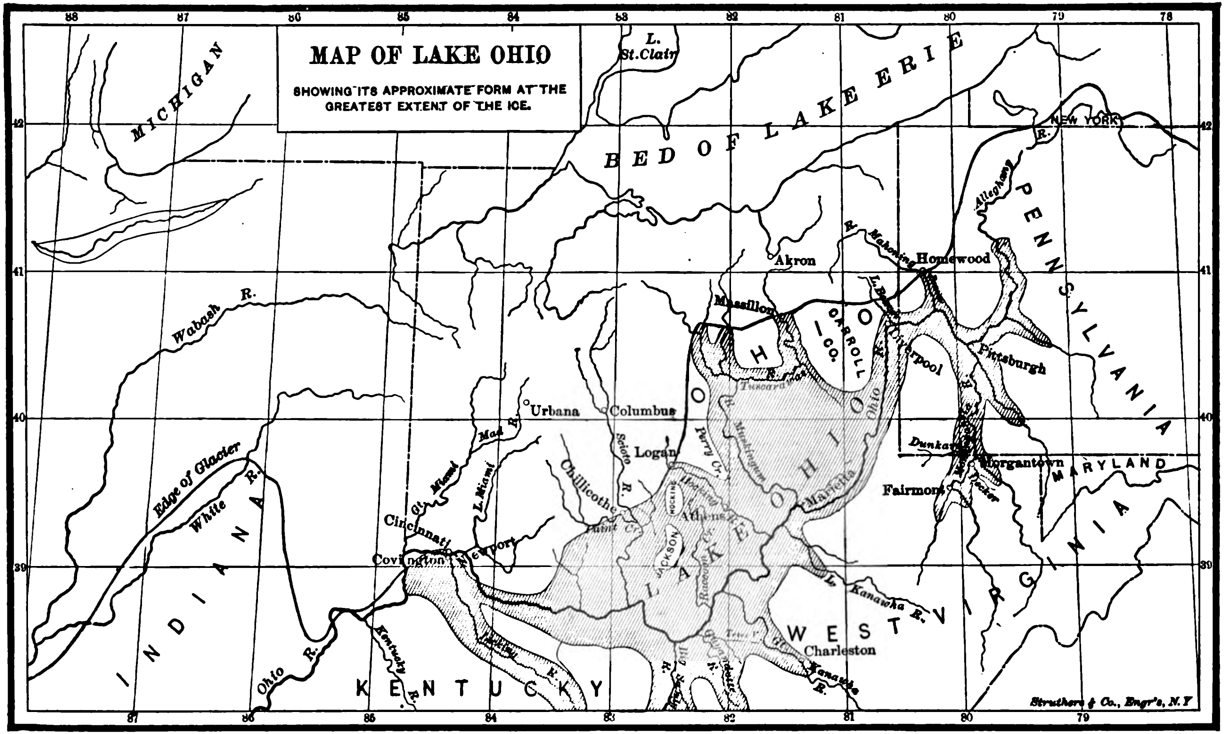

FIG. 54.—Map showing the effect of the glacial dam at Cincinnati (Claypole). (From Transactions of the Edinburgh Geological Society.)

the sea, which is about the height of the water-shed between the Licking and Kentucky Rivers. As the Ohio River occupies a trough of erosion some hundreds of feet in depth, and extending all the way from this point to the mountains of western Pennsylvania, it would follow that the ice which conveyed boulders across the Ohio River at Cincinnati, and deposited them upon the highlands between the Licking and Kentucky Rivers, would so obstruct the channel of the Ohio as to pond the water back, and hold it up to the level of the lowest pass into the Ohio River farther down. Direct evidences of obstruction by glacial ice appear also for a distance of fifty or sixty miles, extending both ways, from Cincinnati.

The consequences connected with this state of things are of the most interesting character.

The bottom of the Ohio River at Cincinnati is 447 feet above the sea-level. A dam of 550 feet would raise the water in its rear to a height of 1,000 feet above tide. This would produce a long, narrow lake, of the width of the eroded trough of the Ohio, submerging the site of Pittsburg to a depth of 300 feet, and creating slack water up the Monongahela nearly to Grafton, West Virginia, and up the Alleghany as far as Oil City. All the tributaries of the Ohio would likewise be filled to this level. The length of this slack-water lake in the main valley, to its termination up either the Alleghany or the Monongahela, was not far from one thousand miles. The conditions were also peculiar in this, that all the northern tributaries rose within the southern margin of the ice-front, which lay at varying distances to the north. Down these there must have poured during the summer months immense torrents of water to strand boulder-laden icebergs on the summits of such high hills as were lower than the level of the dam.

Naturally enough, this hypothesis of a glacial dam at Cincinnati aroused considerable discussion, and led to

some differences of opinion. Professors I. C. White and J. P. Lesley, whose field work has made them perfectly familiar with the upper Ohio and its tributaries, at once supported the theory, with a great number of facts concerning certain high-level terraces along the Alleghany and Monongahela Rivers; while additional facts of the same character have been brought to light by myself and others. In general, it may be said that in numerous places terraces occur at a height so closely corresponding to that of the supposed dam at Cincinnati, that they certainly strongly suggest direct dependence upon it. The upward limit of these terraces in the Monongahela River is 1,065 feet, and they are found in various places in situations which indicate that they were formed in still water of such long standing as would require an obstruction below of considerable permanence.

One of the most decisive cases adduced by Professor White occurs near Morgantown, in West Virginia, of which he gives the following description:

"Owing to the considerable elevation—275 feet—of the fifth terrace above the present river-bed in the vicinity of Morgantown, its deposits are frequently found far inland from the Monongahela, on tributary streams. A very extensive deposit of this kind occurs on a tributary one mile and a half northeast of Morgantown; and the region, which includes three or four square miles, is significantly known as the 'Flats.' The elevation of the 'Flats' is 275 feet above the river, or 1,065 feet above tide. The deposits on this area consist almost entirely of clays and fine, sandy material, there being very few boulders intermingled. The depth of the deposit is unknown, since a well sunk on the land of Mr. Baker passed through alternate beds of clay, fine sand, and muddy trash, to a depth of sixty-five feet without reaching bed-rock. In some portions of the clays which make up this deposit, the leaves of our common forest-trees are found most beautifully preserved."

"At Clarksburg, where the river unites with Elk Creek, there is a wide stretch of terrace deposits, and the upper limit is there about 1,050 feet above tide, or only 130 feet above low water (920 feet); while at Weston, forty miles above (by the river), these deposits cease at seventy feet above low water, which is there 985 feet above tide. It will thus be observed that the upper limit of the deposits retains a practical horizontality from Morgantown to Weston, a distance of one hundred miles, since the upper limit has the same elevation above tide (1,045 to 1,065 feet) at every locality.

"These deposits consist of rounded boulders of sandstone, with a large amount of clay, quicksand, and other detrital matter. The country rock in this region consists of the soft shales and limestones of the upper coal-measures, and hence there are many 'low gaps' from the head of one little stream to that of another, especially along the immediate region of the river; and in every case the summits of these divides, where they do not exceed an elevation of 1,050 feet above tide, are covered with transported or terrace material; but where the summits go more than a few feet above that level we find no transported material upon them, but simply the decomposed country rock."

Other noteworthy terraces naturally attributable to the Cincinnati ice-dam are to be found in the valley of the Kanawha, in West Virginia, and one of special significance on the pass between the valleys of the Ohio and Monongahela, west of Clarksburg, West Virginia. According to Professor White, there is at this latter place "a broad, level summit, having an elevation of 1,100 feet, in a gap about 300 feet below the enclosing hills. This gap, or valley, is covered by a deposit of fine clay. The cut through it is about thirty feet, and one can observe the succession of clays of all kinds and of different colours, from yellow on the surface down to the finest white pot-

ter's clay at the level of the railway, where the cut reaches bed-rock, thus proving that the region has been submerged." *

Another crucial case I have myself described at Bellevue, in the angle of the Ohio and Alleghany Rivers, about five miles below Pittsburg, where the gravel terrace is nearly 300 feet above the river, making it about 1,000 feet above the sea. A significant circumstance connected with this terrace is that not only does its height correspond with that of the supposed obstruction at Cincinnati, but it contains many pebbles of Canadian origin, which could not have got into the valley of the Alleghany before the Glacial period, and could only have reached their present position by being brought down the Alleghany River upon floating ice, or by the ordinary movement of gravel along the margin of a river. Thus this terrace, while corresponding closely with the elevation of those on the Monongahela River, is directly connected with the Glacial period, and furnishes a twofold argument for our theory.

A still stronger case occurs at Beech Flats, at the head of Ohio Brush Creek, in the northwest corner of Pike County, Ohio, where, at an elevation of about 950 feet above the sea, there is an extensive flat-topped terrace just in front of the terminal moraine. This terrace consists of fine loam, such as is derived from the glacial streams, but which must have been deposited in still water. The occurrence of still water at that elevation just in front of the continental ice-sheet is best accounted for by the supposed dam at Cincinnati. Indeed, it is extremely difficult to account for it in any other way.

There are, however, two other methods of attempting to account for the class of facts above cited in support of the ice-dam theory, of which the most plausible is, that in

* Bulletin of the Geological Society of America, vol. i, p. 478.

connection with the Glacial period there was a subsidence of the whole region to an extent of 1,100 feet.

The principal objection heretofore alleged against this supposition is that there are not corresponding signs of still-water action at the same level on the other side of the Alleghany Mountains. This will certainly be fatal to the subsidence theory, if it proves true. But it is possible that sufficient search for such marks has not yet been made on the eastern side of the mountains.

The other theory to account for the facts is, that the terraces adduced in proof of the Cincinnati ice-dam were left by the streams in the slow process of lowering their beds from their former high levels. This is the view advocated by President T. C. Chamberlin. But the freshness of the leaves and fragments of wood, such as were noted by Professor White at Morgantown, and the great extent of fine silt occasionally resting upon the summits of the water-sheds, as described above, near Clarksburg, bear strongly against it. Furthermore, to account for the terrace described at Bellevue, which contains Canadian pebbles, President Chamberlin is compelled to connect the deposit with his hypothetical first Glacial epoch, and to assume that all the erosion of the Alleghany and Monongahela Rivers, and indeed of the whole trough of the Ohio River, took place in the interval between the "first" and the "second" Glacial periods (for he would connect the glacial deposits upon the south side of the river at Cincinnati with the first Glacial epoch)—all of which, it would seem, is an unnecessary demand upon the forces of Nature, when the facts are so easily accounted for by the simple supposition of the dam at Cincinnati, of which there is also so much independent proof.*

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* See matter discussed more at length in the Ice Age, pp. 326–350, 480–500; Bulletin of the United States Geological Survey, No. 58, pp. 76–100.

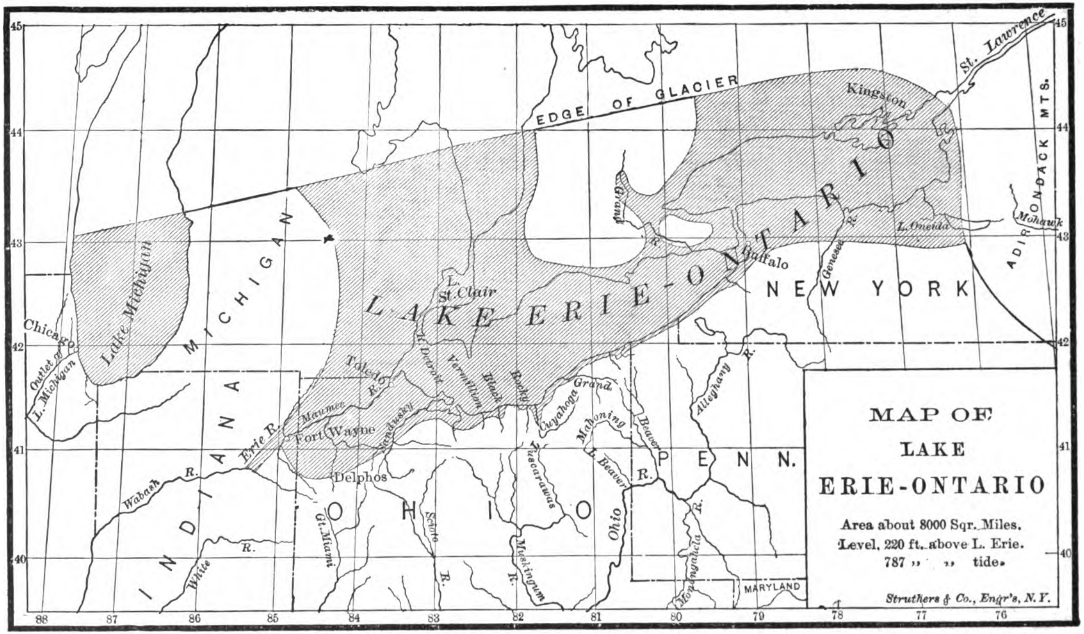

FIG. 55.—Map showing the condition of things when the ice-front had withdrawn about one hundred and twenty miles, and while it still filled the valley of the Mohawk. The outlet was then through the Wabash. Niagara was not yet born (Claypole). (Transactions of the Edinburgh Geological Society.)

We have already described * the various temporary lakes and lines of drainage caused by the direct obstruction of the northward outlets to the basin of the Great Lakes. In connection with the map, it will be unnecessary to do anything more here than add a list of such temporary southern outlets from the Erie-Ontario basin.† The first is at Fort Wayne, Indiana, through a valley connecting the Maumee River basin with that of the Wabash. The channel here is well defined, and the high-level gravel terraces down the Wabash River are a marked characteristic of the valley. The elevation of this col above the sea is 740 feet. Similar temporary lines of drainage existed from the St. Mary's River to the Great Miami, at an elevation of 942 feet; from the Sandusky River to the Scioto, through the Tymochtee Gap, at an elevation of 912 feet; from Black River to the Killbuck (a tributary of the Muskingum) through the Harrisville Gap, at 911 feet; from the Cuyahoga into the Tuscarawas Valley, through the Akron Gap, at 971 feet; from Grand River into the Mahoning, through the Orwell Gap, 938 feet; from Cattaraugus Creek, N. Y., into the Alleghany Valley through the Dayton Gap, about 1,300 feet; between Conneaut Creek and Chenango River, at Summit Station, 1,141 feet; from the Genesee River, N. Y., into the head-waters of the Canisteo, a branch of the Susquehanna, at Portageville, 1,314 feet; from Seneca Lake to Chemung River, at Horseheads, 879 feet; from Cayuga Lake to the valley of Cayuga Creek, at Spencer, N. Y., 1,000 feet; from Utica, N. Y., into the Chenango Valley at Hamilton, about 900 feet.

Perhaps it would have been best to give this list in the reverse order, which would be more nearly chronological, since it is clear that the highest outlets are the oldest. We should then have to mention, after the Fort

* See pp. 92 *seq.*, 199 *seq.* † See also accompanying map.

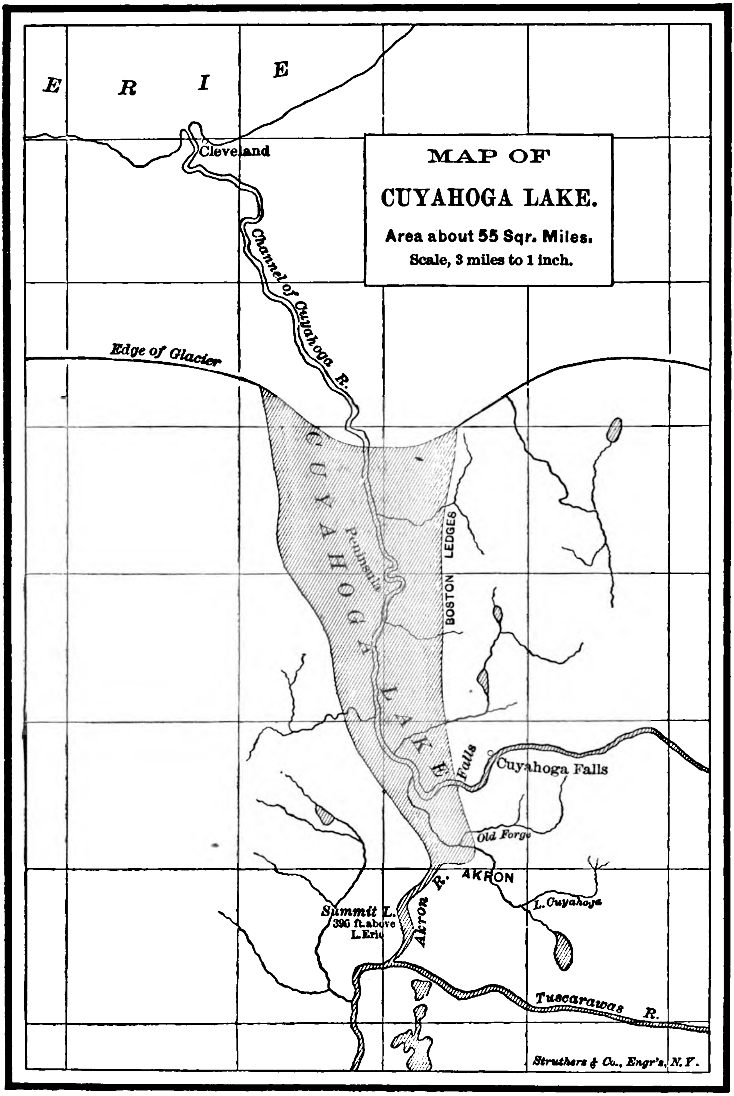

FIG. 56.—Map illustrating a stage in the recession of the ice in Ohio. For a section of the deposit in the bed of this lakelet, see page 200. The gravel deposits formed at this stage along the outlet into the Tuscarawas River are very clearly marked (Claypole). (Transactions of the Edinburgh Geological Society.

Wayne outlet, two others at lower levels which are pretty certainly marked by distinct beach ridges upon the south side of Lake Erie. The first was opened when the ice had melted back from the south peninsula of Michigan to the water-shed across from the Shiawassee and Grand Rivers, uncovering a pass which is now 729 feet above the sea. This continued to be the outlet of Lake Erie-Ontario until the ice had further retreated beyond the Strait of Mackinac, when the water would fall to the level of the old outlet from Lake Michigan into the Illinois River, which is a little less than 600 feet, where it would remain until the final opening of the Mohawk River in New York attracted the water in that direction, and lowered the level to that of the pass from Lake Ontario to the Mohawk at Rome.*

A study of these lines of temporary drainage during the Glacial period sheds much light upon the long lines of gravel ridges running parallel with the shores of Lake Erie and Lake Ontario. South of Lake Erie a series of four ridges of different elevations can be traced. In Lorain County, Ohio, the highest of these is 220 feet above the lake; the next 160 feet; the next 118 feet; and the lower one 100 feet, which would make them respectively 795, 755, 715, and 700 feet above tide.

These gravel ridges are evidently old beach lines, and indicate the different levels up to which the water was held by ice-obstructions across the various outlets of the drainage valley. The material in the ridges is water-worn and well assorted, and in coarseness ranges from fine sand up to pebbles several inches in diameter. The predominant material in them is of local origin. Where the rocks over which they run are sandstone, the material is chiefly sand, and where the outcropping rock is shale, the ridges consist chiefly of the harder nodules of that formation

* Mr. Warren Upham, in the Bulletin of the Geological Society of America, vol. ii, p. 259.

which have successfully resisted the attrition of the waves. Ordinarily these ridges are steepest upon the side facing the lake. According to Mr. Upham, who has driven over them with me, the Lake Erie ridges correspond, both in general appearance and in all other important respects,

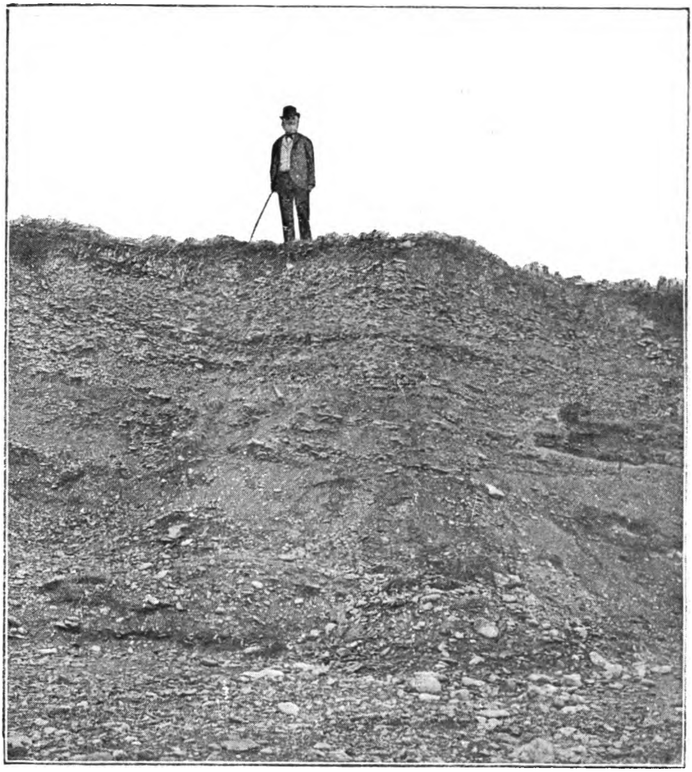

FIG. 57.—Section of the lake ridges near Sandusky, Ohio.

to those which he has so carefully surveyed around the shores of the ancient Lake Agassiz in Minnesota and Manitoba, an account of which will be given a little farther on in this chapter.

We are not permitted, however, to assume that there have been no changes of level since the deposition of these beaches surrounding the ancient glacial Lake Erie-Ontario. On the contrary, there appears to have been a considerable elevation towards the east and northeast in post-glacial times. The highest ridge south of Lake Erie, which at Fort Wayne is about 780 feet high, is now about 795 feet in Lorain County. The second of the ridges above mentioned, which is about 740 feet above tide at Cleveland, Ohio, rises to 870 feet where the last traces of it have been discovered at Hamburg, N. Y. The third ridge, which is 673 feet at Cleveland, has risen to the height of 860 feet at Crittenden, about one hundred miles to the east of Buffalo, N. Y.

A similar eastern increase of elevation is discoverable in the main ridge surrounding Lake Ontario. What Professor Spencer calls the Iroquois beach, which is 363 feet above tide at Hamilton, Ontario, has risen to a height of 484 feet near Syracuse, N. Y.; while farther to the northeast, in the vicinity of Watertown, it is upwards of 800 feet above tide.

There is also a similar northward increase of elevation in the beaches surrounding the higher lands of Ontario eastward of Lake Huron and Georgian Bay.

All this indicates that at the close of the Glacial period there was a subsidence of several hundred feet in the area of greatest ice accumulation lying to the east and north of the Great Lake region. The formation of these ridges occurred during that period of subsidence. The re-elevation which followed the disappearance of the ice of course carried with it these ridges, and brought them to their present position.*

In returning to consider more particularly the remark-

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* See Spencer, in Bulletin of the Geological Society of America, vol. ii, pp. 465–476.

able gorge joining the Minnesota with the Red River of the North, we are brought to the largest of the glacial lakes of this class, and to the typical place in America in which to study the temporary changes of drainage pro-

Fig. 58.—Map showing the stages of recession of the ice in Minnesota as described in the text (Upham).

duced by the ice itself during the periods both of its advance and of its retreat.

By turning to our general map of the glaciated region

of the United States,* one can readily see the relation of the valley between Lake Traverse and Big Stone Lake to an area marked as the bed of what is called Lake Agassiz. During the Glacial period Brown's Valley, the depression joining these two lakes, was the outlet of an immense body of water to the north, whose natural drainage was towards Hudson Bay or the Arctic Ocean, but which was cut off, by the advancing ice, from access to the ocean-level in that direction, and was compelled to seek an exit to the south.

Thus for a long period the present Minnesota River Valley was occupied by a stream of enormous dimensions, and this accounts for the great size of the trough—the present Minnesota being but an insignificant stream winding about in this deserted channel of the old "Father of Waters," and having as much room as a child of tender age would have in his parent's cast-off garments. This glacial stream has been fittingly named River Warren, after General Warren, who first suggested and proved its existence, and so we have designated it on the accompanying map of Minnesota.

Lake Traverse is fifteen miles long, and the water is nowhere more than twenty feet deep. Big Stone Lake is twenty-six miles long, and of about the same depth. Brown's Valley, which connects the two, is five miles long, and the lakes are so nearly on a level that during floods the water from Lake Traverse sometimes overflows and runs to the south as well as to the north.

The trough occupied by these lakes and valley is from one mile to one mile and a half in width and about 120 feet in depth. If we had been permitted to stand upon the bluffs overlooking it during the latter part of the Glacial period, we should have seen the whole drainage of the north passing by our feet on its way to the Gulf of

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* See page 66.

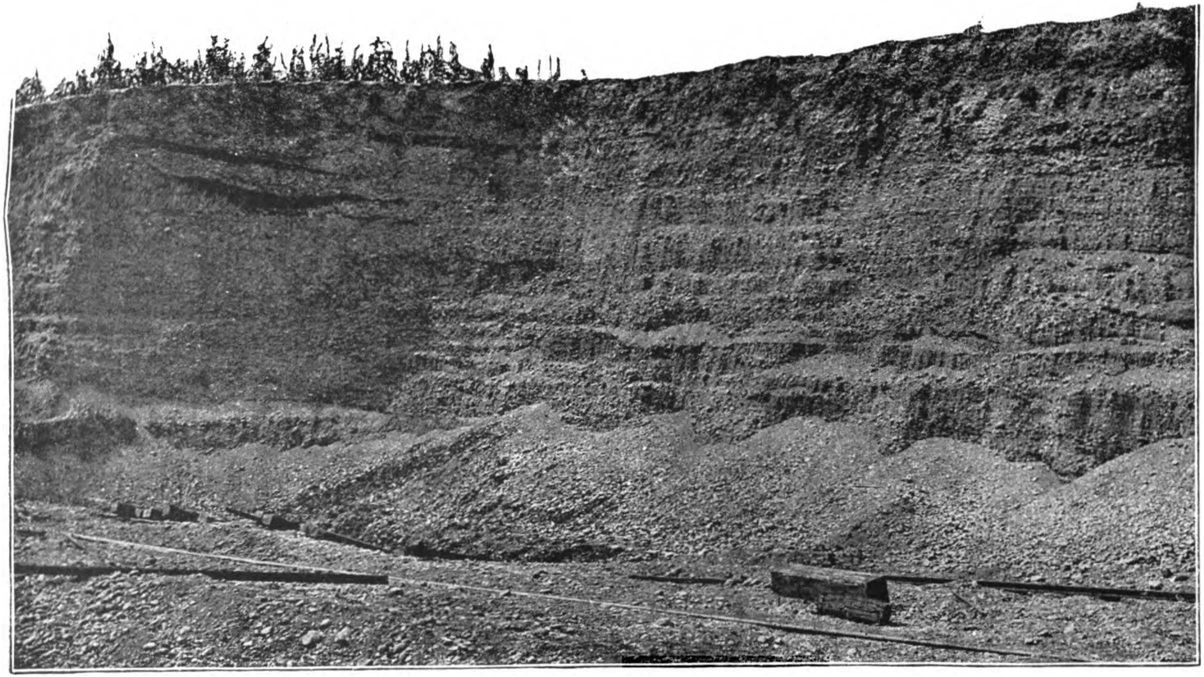

Fig 59.—Glacial terrace near the boundary of the glaciated area, on Raccoon Creek, a tributary of the Licking River, in Granville, Licking County, Ohio. Height about fifty feet.

Mexico. As he follows down the valley of the Minnesota River, the observant traveller, even now, cannot fail to see in the numerous well-preserved gravel terraces the high-water marks of that stream when flooded with the joint product of the annual precipitation over the vast area to the north, and of the still more enormous quantities set free by the melting of the western part of the great Laurentide Glacier.

Numerous other deserted water-ways in the northwestern part of the valley of the Mississippi have been brought to light in the more recent geological surveys, both in the United States and in Canada. During a considerable portion of the Glacial period the Saskatchewan, the Assiniboine, the Pembina, and the Cheyenne Rivers, whose present drainage is into the Red River of the North, were all turned to the south, and their temporary channels can be distinctly traced by deserted water-courses marked by lines of gravel deposits.*

In Dakota, Professor J. E. Todd has discovered large deserted channels on the southwestern border of the glaciated region near the Missouri River, where evidently streams must have flowed for a long distance in ice-channels when the ice still continued to occupy the valley of the James River. From these channels of ice in which the water was held up to the level of the Missouri Coteau the water debouched directly into channels with sides and bottom of earthy material, which still show every mark of their former occupation by great streams.†

In Minnesota, also, there is abundant evidence that while the northeastern part of the valley from Mankato to St. Paul was occupied by ice, the drainage was temporarily turned directly southward across the country through Union Slough and Blue Earth River into the head-waters of the Des Moines River in Iowa.

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* For further particulars, see Ice Age, pp. 293 *et seq.*

† For particulars, see Ice Age, p. 292.

Ancient River Terraces.

The interest of the whole inquiry respecting the relation of man to the Glacial period in America concentrates upon these temporary lines of southern drainage. Wherever they existed, the swollen floods of the Glacial period have left their permanent marks in the deposition of extensive gravel terraces. The material thus distributed is derived largely from the glacial deposits through which they run and out of which they emerge. While the height of the terraces depended upon various conditions which must be studied in detail, in general it may be said that it corresponds pretty closely with the extent of the area whose drainage was turned through the channel during the prevalence of the ice. The height of the terraces and the coarseness of the material seem also to have been somewhat dependent upon the proximity of their valleys to the areas of most vigorous ice-action, and this, in turn, seems to lie in the rear of the moraines which President Chamberlin has attributed to the second Glacial epoch. Southward from this belt of moraines the terraces uniformly and gradually diminish both in height and in the coarseness of their gravel, until they finally disappear in the present flood-plain of the Mississippi River.

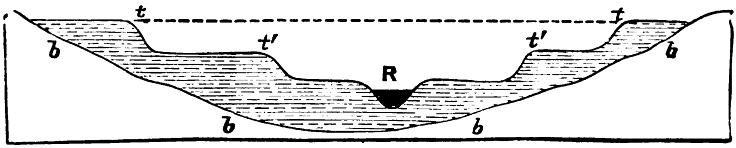

Fig. 60.—Ideal section across a river-bed in drift region: *b b b*, **old river-bed;** *R*, **the present river;** *t t*, **upper or older terraces;** *t' t'*, **lower terraces.**

An interesting illustration of this principle is to be observed in the continuons valley of the Alleghany and Ohio Rivers. The trough of this valley was reached by the continental glacier at only a few points, the ice barely

touching it at Salamanca, N. Y., Franklin, Pa., and Cincinnati, Ohio. But throughout its whole length the ice-front was approximately parallel to the valley, and occupied the head-waters of nearly all its tributaries. Now, wherever tributaries which could be fed by glacial floods, enter the trough of the main stream, they brought down an excessive amount of gravel, and greatly increased the size of the terrace in the trough itself, and from the mouth of each such tributary to that of the next one below there is a gradual decrease in the height of the terrace and in the coarseness of the material.

This law is illustrated with special clearness in Pennsylvania between Franklin and Beaver. Franklin is upon the Alleghany River, at the last point where it was reached directly by the ice. Below this point no tributary reaches it from the glaciated region, and none such reaches the Ohio after its junction with the Alleghany until we come to the mouth of Beaver Creek, about twenty-five miles below Pittsburg.

But at this point the Ohio is joined by a line of drainage which emerges from the glaciated area only ten or twelve miles to the north, and whose branches occupy an exceptionally large glaciated area. Accordingly, there is at Beaver a remarkable increase in the size of the glacial terrace on the Ohio. In the angle down-stream between the Beaver and the Ohio there is an enormous accumulation of granitic pebbles, many of them almost large enough to be called boulders, forming the delta terrace, upon which the city is built and rising to a height of 135 feet above the low-water mark in the Ohio. In striking confirmation of our theory, also, the terrace in the Ohio Valley upon the upper side of Beaver Creek is composed of fine material, largely derived from local rocks and containing but few granitic pebbles.

From the mouth of Beaver Creek, down the Ohio, the terrace is constant (sometimes upon one side of the river

and sometimes upon the other), but, according to rule, the material of which it is composed gradually grows finer, and the elevation of the terrace decreases. According to rule, also, there is a notable increase in the height of the terrace below each affluent which enters the river from the glaciated region. This is specially noticeable below Marietta, at the mouth of the Muskingum, whose head-waters drain an extensive portion of the glaciated area. From the mouth of the Little Beaver to this point the tributaries of the Ohio are all small, and none of them rise within the glacial limit. Hence they could contribute nothing of the granitic material which enters so largely into the formation of the river terrace; but below the mouth of the Muskingum the terrace suddenly ascends to a height of nearly one hundred feet above low-water mark.

Again, at the mouth of the Scioto at Portsmouth, there is a marked increase in the size of the terrace, which is readily accounted for by the floods which came down the Scioto Valley from the glaciated region. The next marked increase is at Cincinnati, just below the mouth of the Little Miami, whose whole course lay in the glaciated region, and whose margin is lined by very pronounced terraces. At Cincinnati the upper terrace upon which the city is built is 120 feet above the flood-plain.

Twenty-five miles farther down the river, near Lawrenceburg, these glacial terraces are even more extensive, the valley being there between three and four miles wide, and being nearly filled with gravel deposits to a height of 112 feet above the flood-plain. Below this point the terraces gradually diminish in height, and the material becomes finer and more water-worn, until it merges at last in the flood-plain of the Mississippi. The course of the Wabash River is too long to permit it to add materially to the size of the terraces which characterise the broader valley of the Ohio below the Illinois line.

It is in terraces such as these just described that we find

the imbedded relics of man which definitely connect him with the great Ice age. These have now been found in the glacial terraces of the Delaware River at Trenton, N. J.; in similar terraces in the valley of the Tuscarawas River at New Comerstown, and in the valley of the Little Miami at Loveland and Madisonville, in Ohio; on the East Fork of White River, at Medora, Ind.; and still, again, at Little Falls, in the trough of the Mississippi, some distance above Minneapolis, Minn.

I append a list of the points at which various streams from the Atlantic Ocean to the Mississippi River emerge from the glacial boundary, and below which the terraces are specially prominent. Of course, with the retreat of the ice, the formation of the terraces continued northward in the glaciated area to a greater or less distance, according to the extent of the valley or to the length of time during which the drainage was temporarily turned into it. These points of emergence are: In the Delaware Valley, at Belvidere, N. J.; in the Susquehanna, at Beach Haven, Pa.; in the Conewango, at Ackley, Warren County; in Oil Creek, above Titusville; in French Creek, a little above Franklin; in Beaver Creek, at Chewtown, Lawrence County; on the Middle Fork of Little Beaver, near New Lisbon, Ohio; on the east branch of Sandy Creek, at East Rochester, Columbiana County; on the Nimishillin, at Canton, Stark County; on the Tuscarawas, at Bolivar; on Sugar Creek, at Beech City; on the Killbuck, at Millersburg, Holmes County; on the Mohican, near the northeast corner of Knox County; on the Licking River, at Newark; on Jonathan Creek, Perry County; on the Hocking, at Lancaster; on the Scioto, at Hopetown, just above Chillicothe; on Paint Creek, and its various tributaries, between Chillicothe and Bainbridge; and on the Wabash, above New Harmony, Ind.; to which may be added the Ohio River itself, at its junction with the Miami, near Lawrenceburg.

Another class of terraces having most interesting connection with the Glacial period is found in the arid basins west of the Rocky Mountains. Over wide areas in Utah and Nevada the evaporation now just balances the precipitation, and all the streams disappear in shallow bodies of salt water of moderate dimensions, of which Great Salt Lake in Utah, and Mono, Pyramid, and North Carson Lakes in Nevada, are the most familiar examples. These occupy the lowest sinks of enclosed basins of great depth.

But there is abundant evidence that in consequence of the increased precipitation and diminished evaporation of the Glacial period one of these basins was filled to the brim and the other to a depth of several hundred feet. These former enlargements have been named after the first explorers of the region, Captains Lahontan and Bonneville, and are shown on the accompanying sketch map by the shading surrounding the existing lakes.

Lake Lahontan has been carefully studied by Mr. I. C. Russell, and has been found to extend from the boundary of Oregon to latitude 38° 30′ south, a distance of two hundred and sixty miles. The Central Pacific Railroad runs through its dried-up bed from Golconda to Wadsworth, a distance of one hundred and sixty-five miles. The terraces of the former lake are distinctly traceable at a height of 700 feet above the present level of Lake Mono.

Lake Bonneville, whose present representative is Great Salt Lake, is the subject of a recent monograph by Mr. G. K. Gilbert, from which it appears that this ancient body of water occupied 19,750 square miles—an area about ten times that of the present lake. At the time of its maximum extension its depth was 1,000 feet, while Great Salt Lake ranges only from fifteen to fifty feet in depth.

The pass through which the discharge finally took place is at Red Rock, on the Utah and Northern Railroad, at the head of Cache Valley on the south and the lower

part of Marsh Creek Valley on the north. During the long period preceding and accompanying the gradual rise of water in the Utah basin to the level of the highest ter-

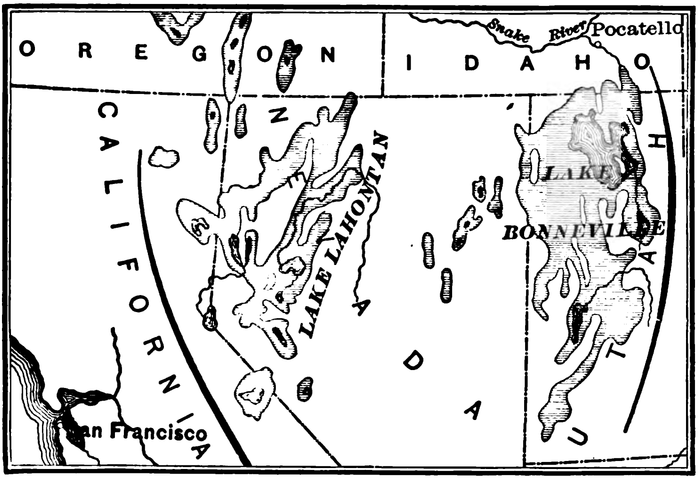

FIG. 61.—Map of the Quaternary Lakes, Bonneville and Lahontan (after Gilbert and Russell).

race, Marsh Creek (the upper portion of which comes from the mountains on the east and turns at right angles) had been at work depositing a delta of loose material in the col which separates the two valleys. This deposit rested upon a stratum of limestone at the bottom of the pass, and covered it with sand, clay, and gravel to a depth of 375 feet. Thus, when the water was approaching its upper level, the only barrier to prevent its escape was this unstable accumulation of loose material upon top of the rock. It would have required, therefore, no prophet's eye to predict that the way was preparing for a tremendous *débâcle.*

The critical point at length was reached. After remaining nearly at the elevation of the pass for a considerable period, during which the 1,000-foot shore-line was formed,

the crisis came when the water began to flow northward towards Snake River. Once begun in such loose material, the channel rapidly enlarged until soon a stream equal to Niagara, and at times probably much larger, was pouring northward through the valley heretofore occupied by the insignificant rivulets of Marsh Creek and the Port Neuf. It is impossible to tell how rapidly the loose barrier wore away, but there is abundant evidence in the valley below that not only the present channel of the lower part of Marsh Creek, but the whole bottom of the valley for a mile or more in width, was for a considerable time covered by a rapid stream from ten to twenty feet in depth, and descending at the rate of thirteen feet to the mile.

The continuance of this flood was dependent upon the amount of water to be discharged, which, as we have seen, was that contained in an area of 20,000 square miles, with a depth of 375 feet. A stream of the size of Niagara would occupy about twenty-five years in the discharge of such a mass, and this may fairly be taken as a measure of the time through which it lasted. When the loose material lying above the strata of limestone in Red Rock Pass had been washed away, the lake then continued at that level for an indefinite period, with an overflow regulated by the annual precipitation of the drainage basin. This stage of the lake, during which it occupied 13,000 square miles and was 625 feet above its present level, is also marked by an extensive and persistent shore-line all around the basin. But, finally, the balance again turned when the evaporation exceeded the precipitation, and the vast body of water has since dwindled to its present insignificant dimensions.

My own interest in this discovery of Mr. Gilbert is enhanced by the explanation it gives of a phenomenon in the Snake River Valley which I was unable to solve when on the ground in 1890. The present railroad town of

Pocatello is situated just where this flood emerged from the narrower valley of Marsh Creek and the Port Neuf, and spread itself out upon the broad plain of the Snake River basin. The southern edge of the plain upon which the city is built is a vast boulder-bed covered with a thin stratum of sand and gravel. Everywhere, in sinking wells and digging ditches on the vacant lots and in the streets of the city, water-worn boulders of a great variety of material and sometimes three or four feet in diameter are encountered. I was debarred from regarding this as a terminal moraine, both by the water-worn character of the boulders and by the absence of any sign of ice-action in the surrounding mountains, and I was equally debarred from attributing it to any ordinary stream of water, both by the size of the boulders and the fact that for a mile or more up the Port Neuf Valley there is an intervale, forty or fifty feet below the surface at Pocatello, and occupying the whole width of the valley, in which there is only gravel and fine sand, through which the present Port Neuf pursues a meandering course. The upper end of this short intervale is bounded by the terminus of a basaltic stream which had flowed down the valley and filled it to a considerable depth, but had subsequently been much eroded by violent water-action.

In the light of Mr. Gilbert's discoveries, however, everything is clear. The tremendous *débâcle* which he has brought within the range of scientific vision would naturally produce just the condition of things which is so puzzling at Pocatello. Coming down through the restricted channel with sufficient force to roll along boulders of great size and to clear them all out from the upper portion of the valley, the torrent would naturally deposit them where the current was first checked, a mile below the lava cliffs. The plunge of the water over these cliffs would keep a short space below clear from boulders, and the more moderate stream of subsequent times would fill

in the depression with the sand and gravel now occupying it.

What other effects of this remarkable outburst may be traced farther down in the Snake River Valley I cannot say, but it will be surprising if they do not come to light and help to solve some of the many geological problems yet awaiting us in this interesting region.

It should have been said that during the formation of the 625-foot, or so-called Provo shore-line, glaciers descended from the cañons on the west flank of the Wahsatch Mountains, and left terminal moraines to mark the coincidence of the Glacial period with that stage of the enlargement of the lake. Evidences of a similar coincidence are to be found on the high-level terraces surrounding Lake Mono, to which glaciers formerly descended from the western flanks of the Sierra Nevada.

The ancient shore-lines surrounding Lakes Bonneville and Lahontan bear evidence also of various other episodes in the Glacial period. Evidently there were two periods of marked increase in the size of the lakes, with an arid period intervening. During the first rise the level of Bonneville attained to within ninety feet of the second, and numerous beaches were formed, and a large amount of yellow clay deposited. Then it seems to have been wholly evaporated, while its soluble mineral matter was precipitated, and so mingled with silt that it did not readily redissolve during the second great rise of water. Partly on this account, and partly through the influence of the outlet into the Snake River, the lake was nearly fresh during its second enlargement.

European Facts.

In Chapter VI it came in place to mention many of the facts connected with the influence of the Glacial period upon the drainage systems of Europe. We there discussed briefly the probable influence of the ice-obstructions

that extended across the mouths of the Dwina, the Vistula, the Oder, the Elbe, the Weser, and the Rhine. The drainage of the obstructed rivers in Russia was perhaps turned southward into the Caspian and Black Seas, and then assisted in forming the fertile soil of the plains in the southern part of that empire.

The obstructed drainage of the German rivers was probably turned westward in front of the ice through the Straits of Dover or across the southern part of England. This was during the climax of the Glacial period; but later, according to Dawkins, during a period in which the land of the British Isles stood about 600 feet above its present level, the streams of the eastern coast—namely, "the Thames, Medway, Humber, Tyne, and others, joined the Rhine, the Weser, and the Elbe, to form a river flowing through the valley of the ocean. In like manner, the rivers of the south of England and of the north of France formed a great river flowing past the Channel Islands due west into the Atlantic, and the Severn united with the rivers of the south of Ireland; while those to the east of Ireland joined the Dee, Mersey Ribble, and Lune, as well as those of western Scotland, ultimately reaching the Atlantic to the west of the Hebrides. The water-shed between the valleys of the British Channel and the North Sea is represented by a ridge passing due south from Folkestone to Dieppe, and that between the drainage area and the Severn and its tributaries on the one hand, and of the Irish Channel on the other, by a ridge from Holyhead westward to Dublin.

"This tract of low, undulating land which surrounded Britain and Ireland on every side consisted not merely of rich hill, valley, and plain, but also of marsh-land studded with lakes, like the meres of Norfolk, now indicated by the deeper soundings. These lakes were very numerous to the south of the Isle of Wight and off the coast of Norfolk and Suffolk." *

* Early Man in Britain, p. 151.

The evidence first regarded by scientific men to be demonstrative of the formation of extensive lakes during the Glacial period by the direct influence of ice-dams exists in the Parallel Roads of Glen Roy in Scotland.

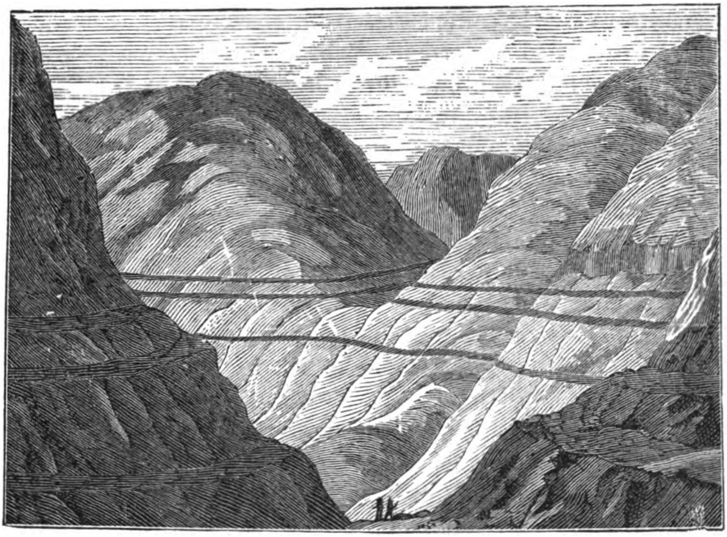

FIG. 62.—Parallel roads of Glen Roy.

According to the description of Sir Charles Lyell, "Glen Roy is situated in the western Highlands, about ten miles north of Fort William, near the western end of the great glen of Scotland, or Caledonian Canal, and near the foot of the highest of the Grampians, Ben Nevis. Throughout nearly its whole length, a distance of more than ten miles, three parallel roads or shelves are traced along the steep sides of the mountains, each maintaining a perfect horizontality, and continuing at exactly the same level on the opposite sides of the glen. Seen at a distance they appear like ledges, or roads, cut artificially out of the sides of the hills; but when we are upon them, we can scarcely recognize their existence, so uneven is their sur-

face and so covered with boulders. They are from ten to sixty feet broad, and merely differ from the side of the mountain by being somewhat less steep.

"On closer inspection, we find that these terraces are stratified in the ordinary manner of alluvial or littoral deposits, as may be seen at those points where ravines have been excavated by torrents. The parallel shelves, therefore, have not been caused by denudation, but by the deposition of detritus, precisely similar to that which is dispersed in smaller quantities over the declivities of the hills above. These hills consist of clay-slate, mica-schist, and granite, which rocks have been worn away and laid bare at a few points immediately above the parallel roads. The lowest of these roads is about 850 feet above the level of the sea, and the next about 212 feet higher, and the third 82 feet above the second. There is a fourth shelf, which occurs only in a contiguous valley called Glen Gluoy, which is twelve feet above the highest of all the Glen Roy roads, and consequently about 1,156 feet above the level of the sea. One only, the lowest of the three roads of Glen Roy, is continued through Glen Spean, a large valley with which Glen Roy unites. As the shelves, having no slope towards the sea like ordinary river terraces, are always at the same absolute height, they become continually more elevated above the river in proportion as we descend each valley; and they at length terminate very abruptly, without any obvious cause, or any change either in the shape of the ground or in the composition or hardness of the rocks." *

Early in his career Charles Darwin studied these ancient beaches, and ascribed them to the action of the sea during a period of continental subsidence. In this view he was supported by the majority of geologists until the region was visited by Agassiz, who saw at once the true explanation. If these were really sea-beaches, similar de-

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* Antiquity of Man, pp. 252, 253.

posits should be found at the same elevation on other mountains than those surrounding Glen Roy. Their absence elsewhere points, therefore, to some local cause, which was readily suggested to the trained eye of one like Agassiz, then fresh from the study of Alpine glaciers, who saw that these beaches were formed upon the margin of temporary lakes, held back during the Glacial period (as the Merjelen See now is) by a glacier which came out of one glen and projected itself directly across the course of another, and thus obstructed its drainage. The glacier of Glen Spean had pushed itself across Glen Roy, as the great Aletsch Glacier in Switzerland now pushes itself across the little valley behind the Eggishorn.

CHAPTER VIII.

RELICS OF MAN IN THE GLACIAL PERIOD.

In Glacial Terraces of the United States.

ALTHOUGH the first clear evidence of glacial man was discovered in Europe, the problem is so much simpler on the Western Continent that we shall find it profitable to study the American facts first. We will therefore present a summary of them at once, and then proceed to the more obscure problems of European archæology.

The first definite discovery of human relics clearly connected with glacial deposits in America, and of the same age with them, was made by Dr. C. C. Abbott, at Trenton, N. J., in the year 1875. The city of Trenton is built upon a delta terrace about three miles wide which occurs at the head of tide-water on the Delaware River. This terrace bears every mark of having been deposited by a torrential stream which came down the valley during the closing period of the great Ice age. The material of which the terrace consists is all water-worn. According to the description of Professor N. S. Shaler:

"The general structure of the mass is neither that of ordinary boulder-clay nor of stratified gravels, such as are formed by the complete rearrangement by water of the elements of simple drift-deposits. It is made up of boulders, pebbles, and sand, varying in size from masses containing one hundred cubic feet or more to the finest sand of the ordinary sea-beaches. There is little trace of true clay in the deposit; there is rarely enough to give the

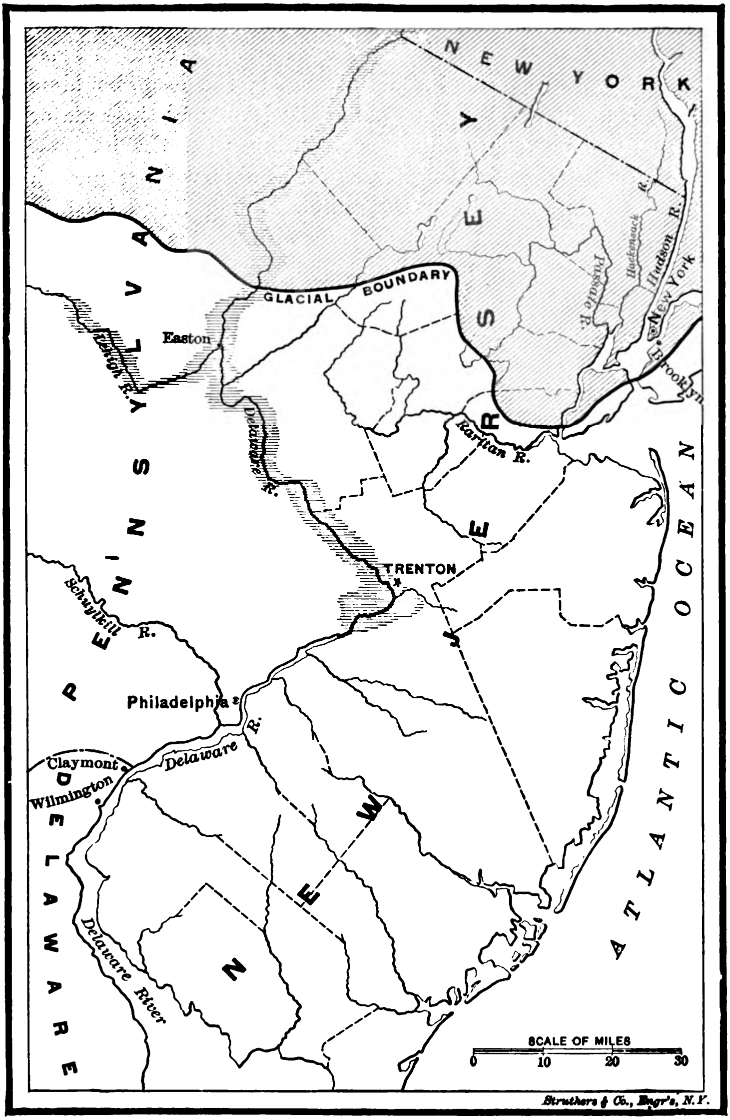

FIG. 63.—The glaciated portion is shaded. The shading on the Lehigh and Delaware Rivers indicates glacial terraces, which are absent from the Schuylkill.

least trace of cementation to the masses. The various elements are rather confusedly arranged; the large boulders not being grouped on any particular level, and their major axes not always distinctly coinciding with the horizon. All the pebbles and boulders, so far as observed, are smooth and water-worn, a careful search having failed to show evidence of distinct glacial scratching or polishing on their surfaces. The type of pebble is the subovate or discoidal, and though many depart from this form, yet nearly all observed by me had been worn so as to show that their shape had been determined by running water. The materials comprising the deposit are very varied, but all I observed could apparently with reason be supposed to have come from the extensive valley of the river near which they lie, except perhaps the fragments of some rather rare hypogene rocks."

A conclusive proof of the relation of this Trenton delta terrace to the Glacial period is found in the fact that the gravel deposit is continuous with terraces extending up the trough of the valley of the Delaware to the glaciated

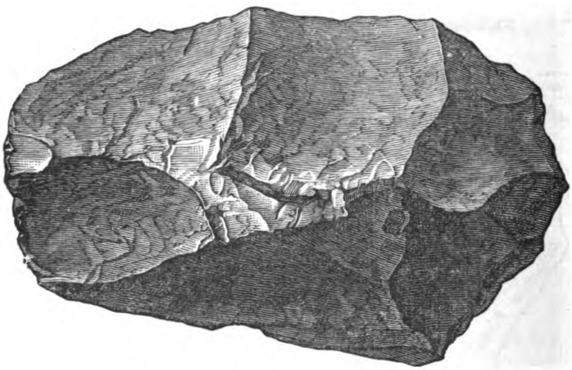

FIG. 64.—Palæolith found by Abbott in New Jersey, slightly reduced.

area and beyond. As, however, the descent of the river-bed is rapid (about four feet to the mile) from the glacial

border down to tide-water, the terrace is not remarkably high, being only about fifteen or twenty feet above the present flood-plain. But it is continuous, and similar in composition with the great enlargement in the delta at Trenton. Without doubt, therefore, the deposit represents the overwash gravel of the Glacial period.

Fortunately for science, Dr. C. C. Abbott, whose tastes for archæological investigations were early developed, had his residence upon the border of this glacial delta terrace at Trenton, and as early as 1875 began to find rough-stone implements of a peculiar type in the talus of the bank where the river was undermining the terrace. In turning his attention to the numerous fresh exposures of gravel made by railroad and other excavations during the following year, he found several of the implements in undisturbed strata, some of which were sixteen feet below the surface. Since that time he has continued to make discoveries at various intervals. In 1888 he had found four hundred implements of the palæolithic type at Trenton, sixty of which had been taken from recorded depths in the gravel, two hundred and fifty from the talus at the bluff facing

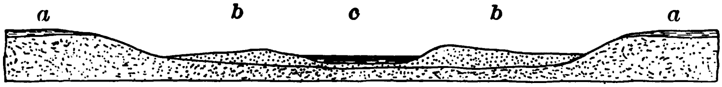

FIG. 65.—Section across the Delaware River at Trenton, New Jersey: *a, a*, Philadelphia red gravel and brick clay (McGee's Columbia deposit); *b, b*, Trenton gravel, in which the implements are found; *c*, present flood-plain of the Delaware River (after Lewis). (From Abbott's Primitive Industry.)

the river, and the remainder from the surface, or derived from collectors who did not record the positions or circumstances under which they were found.

The material from which the implements at Trenton are made is argillite—that is, a clay slate which has been so metamorphosed as to be susceptible of fracture, almost like flint. It is, however, by no means capable of being worked into such delicate forms as flint is. But as it is

the only material in the vicinity capable of being chipped, prehistoric men of that vicinity were compelled to make a

FIG. 66.—Section of the Trenton gravel in which the implements described in the text are found. The shelf on which the man stands is made in process of excavation. The gravel is the same above and below (photograph by Abbott).

virtue of necessity and use the inferior material. Of all the implements found by Dr. Abbott in the gravel, only one was flint; while upon the surface innumerable arrowheads of flint have been found. The transition, also, in the type of implements is as sudden as that in the kind of material of which they are made. Below the superficial deposit of black soil, extending down to the depth of about one foot, the modern Indian flint implements entirely

disappear, and implements of palæolithic type only are found.

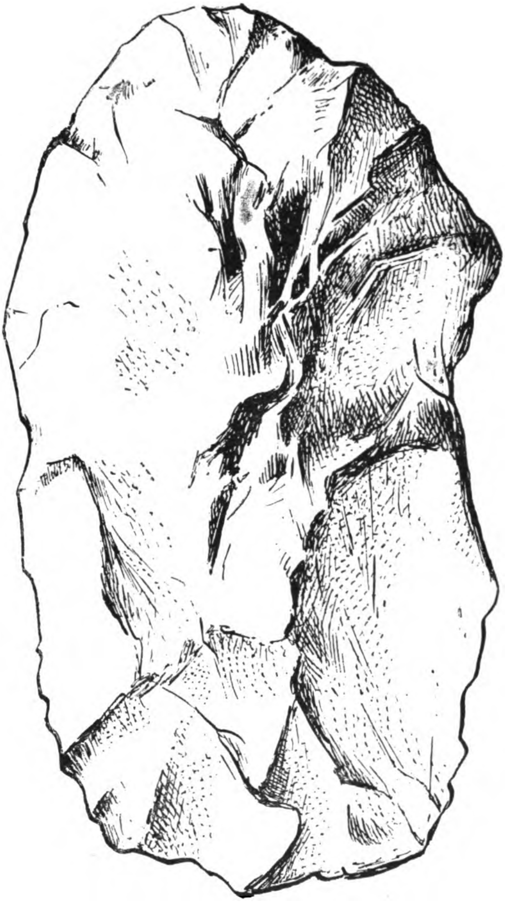

FIG. 67.—Face view of argillite implement, found by Dr. C. C. Abbott, in 1876, at Trenton, New Jersey, in gravel, three feet from face of bluff, and twenty-two feet from the surface (No. 10,985) (Putnam).

In the year 1882, after I had traced the glacial boundary westward from the Delaware River, across the States of Pennsylvania, Ohio, and Indiana, I was struck with

the similarity between the terrace at Trenton and numerous terraces which I had attributed to the Glacial age in

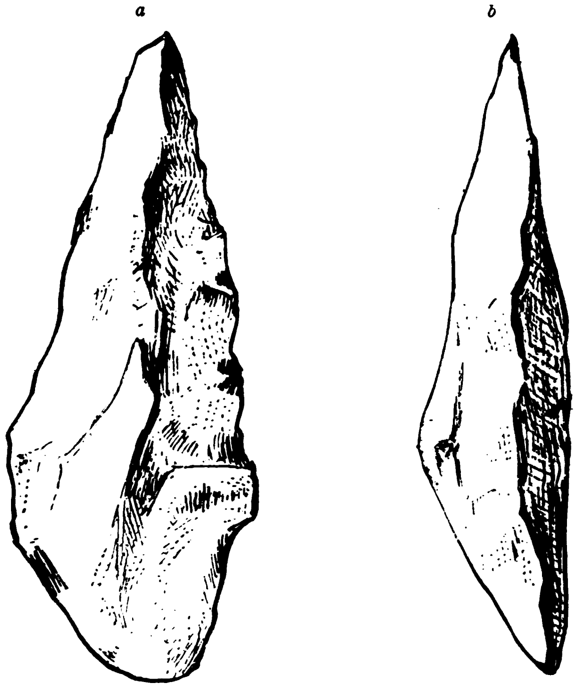

FIG. 68.—Argillite implement found by Dr. C. C. Abbott, March, 1879, at A. K. Rowan's farm, Trenton, New Jersey, in gravel sixteen feet from surface: *a*, face view; *b*, side view (No. 11,286) (Putnam).

Ohio and the other States. It adds much to the interest of subsequent discoveries to note that in 1884, in my report to the Western Reserve Historical Society upon the glacial boundary of Ohio, I wrote as follows:

"The gravel in which they [Dr. Abbott's implements] are found is glacial gravel deposited upon the banks of the Delaware when, during the last stages of the Glacial period, the river was swollen with vast floods of water from the melting ice. Man was on this continent at that period

when the climate and ice of Greenland extended to the mouth of New York Harbor. The probability is, that if he was in New Jersey at that time, he was also upon the banks of the Ohio, and the extensive terrace and gravel

a *b*

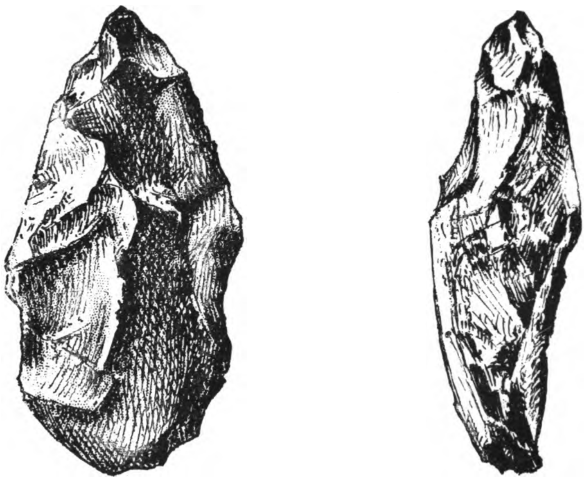

Fig. 69.—Chipped pebble of black chert, found by Dr. C. L. Metz, October, 1885, at Madisonville, Ohio, in gravel eight feet from surface under clay: *a*, face view; *b*, side view.

deposits in the southern part of our State should be closely scanned by archæologists. When observers become familiar with the rude form of these palæolithic implements, they will doubtless find them in abundance. But whether we find them or not in this State [Ohio], if you admit, as I am compelled to do, the genuineness of those found by Dr. Abbott, our investigation into the glacial phenomena of Ohio must have an important archæological significance, for they bear upon the question of the chronology of the Glacial period, and so upon that of man's appearance in New Jersey."

The expectation of finding evidence of preglacial man in Ohio was justified soon after this (in 1885), when Dr. C

L. Metz, while co-operating with Professor F. W. Putnam, of the Peabody Museum, Cambridge, Mass., in field work, discovered a flint implement of palæolithic type in undisturbed strata of the glacial terrace of the Little Miami River, near his residence at Madisonville, Ohio. In 1887 Dr. Metz found another implement in the terrace of the

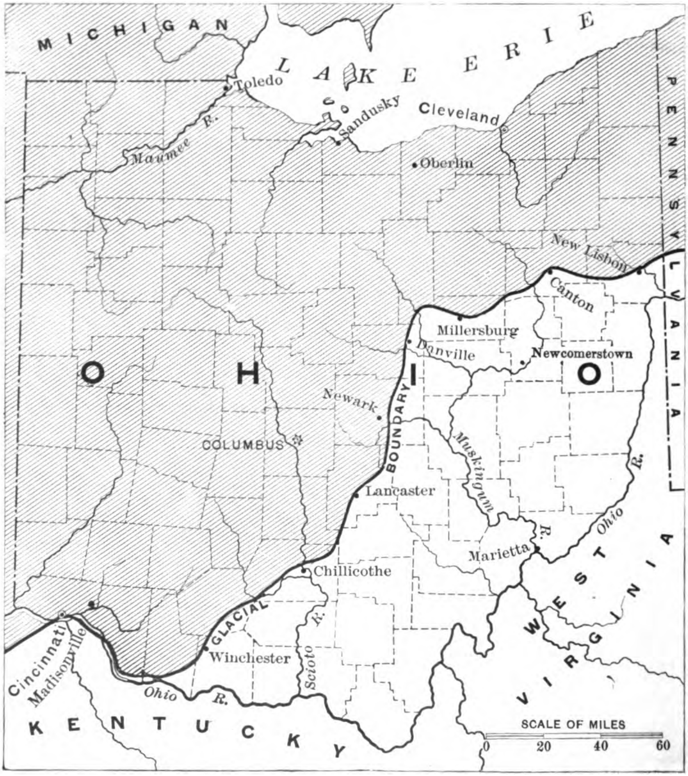

FIG. 70.

same river, at Loveland, about twenty-five miles farther up the stream. The implement at Madisonville occurred eight feet below the surface, and about a mile back from

the edge of the terrace; while that at Loveland was found in a coarser deposit, about a quarter of a mile back from the present stream, and thirty feet below the surface. Mastodon-bones also were discovered in close proximity to the implement at Loveland.

Interest in these investigations was still further increased by the report of Mr. Hilborne T. Cresson, of Philadelphia, that in 1886, with my map of the glaciated region in hand, he had found an implement of palæolithic type in undisturbed strata of the glacial terrace bordering the East Branch of White River, near the glacial boundary at Medora, Jackson County, Ind. The terrace was about fifty feet above the flood-plain of the river.

Later still, in October, 1889, Mr. W. C. Mills, of Newcomerstown, Tuscarawas County, Ohio, found in that town a finely shaped flint implement sixteen feet below the surface of the terrace of glacial gravel which lines the margin of the Tuscarawas Valley.* Mr. Mills was not aware of the importance of this discovery until meeting with me some months later, when he described the situation to me, and soon after sent the implement for examination. In company with Judge C. C. Baldwin, President of the Western Reserve Historical Society, and several others, a visit was made to Mr. Mills, and we carefully examined the gravel-pit in which the implement occurred, and collected evidence which was abundant to corroborate all his statements. The implement in question is made from a peculiar flint which is found in the Lower Mercer limestone, of which there are outcrops a few miles distant, and it resembles in so many ways the typical implements found by Boucher de Perthes, at Abbeville, that, except for the difference in the material from which it is made, it would be impossible to distinguish it from them. The similarity

* For typical section of a glacial terrace in Ohio, see p. 227.

of pattern is too minute to have originated except from imitation.

In 1877, a year after the discoveries by Dr. Abbott in New Jersey, some rudely chipped flints were discovered

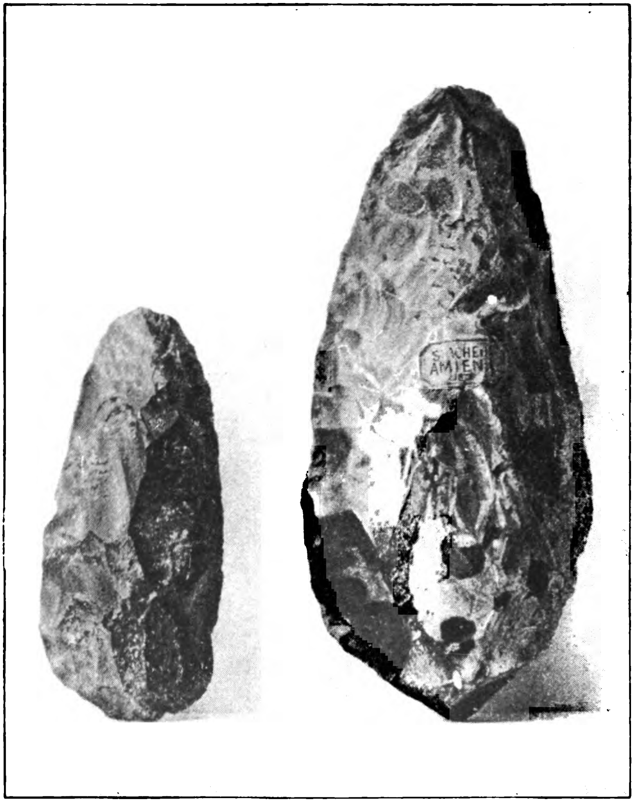

FIG. 71.—The smaller is the palæolith from Newcomerstown, the larger from Amiens (face view), reduced one half in diameter.

by Professor N. H. Winchell in the glacial terraces of the upper Mississippi, in the vicinity of Little Falls, Morrison County, Minn. This locality was afterwards more fully

explored by Miss Franc E. Babbitt, who succeeded in finding so large a number of the implements as to set at rest

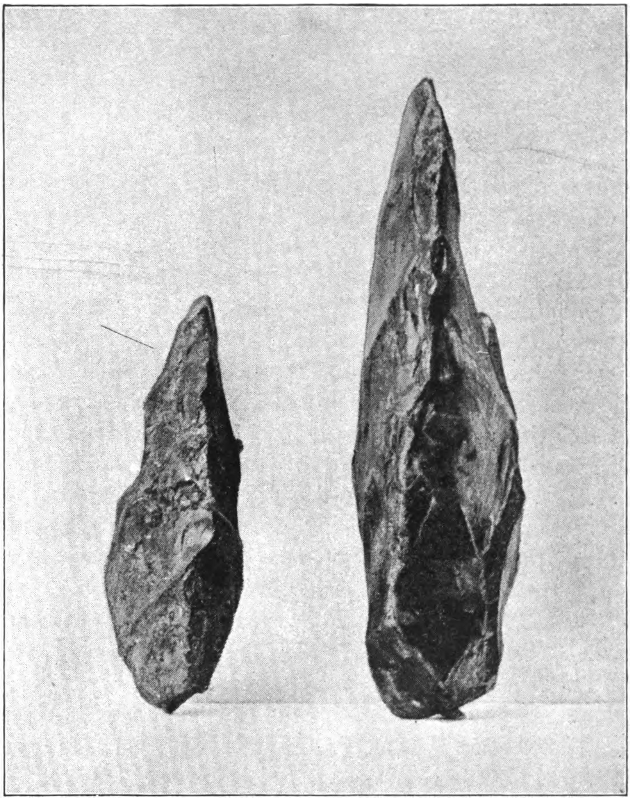

FIG. 72.—Edge view of the preceding.

all question concerning their human origin. According to Mr. Warren Upham, the glacial flood-plain of the Mississippi is here about three miles wide, with an elevation of from twenty-five to thirty feet above the river. It is in a stream near the bottom of this glacial terrace that the most of Miss Babbitt's discoveries were made, and Mr.

Upham has pretty clearly shown that the gravel of the terrace overlying them was mostly deposited while the ice-

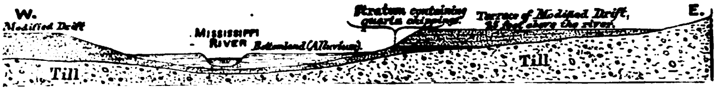

Fig. 73.—Section across the Mississippi Valley at Little Falls, Minnesota, showing the stratum in which chipped quartz fragments were found by Miss F. E. Babbitt, as described in the text (Upham).

front was still lingering about sixty miles farther north, in the vicinity of Itasca Lake.*

Up to this time the above are all the instances in which the relics of man are directly and indubitably connected with deposits of this particular period east of the Rocky Mountains. Probably it is incorrect to speak of these as preglacial, for the portion of the period at which the deposits incorporating human relics were made is well on towards the close of the great Ice age, since these terraces were, in some cases, and may have been in all cases, deposited after the ice-front had withdrawn nearly, if not quite, to the water-shed of the St Lawrence basin. It may be difficult to demonstrate this with reference to the gravel deposits at Trenton, Madisonville, and Medora, but it is evident at a glance in the case of Newcomerstown and Little Falls.

That the implement-bearing gravel of Trenton, N. J., belongs to the later stages of the Glacial period is evident from its relation to what Professor H. Carvill Lewis called "the Philadelphia red gravel and brick-clay," but which, from its large development in the District of Columbia at Washington, is called by Mr. McGee the "Columbia deposit." The city of Philadelphia is built upon this formation in the Delaware Valley, and the brick for its houses is obtained from it; the cellar of each house ordinarily furnishing clay enough for its brick walls. This clay is

* For a general map, see p. 66; also p. 225.

of course a deposit in comparatively still water, which would imply deposition during a period of land subsidence.

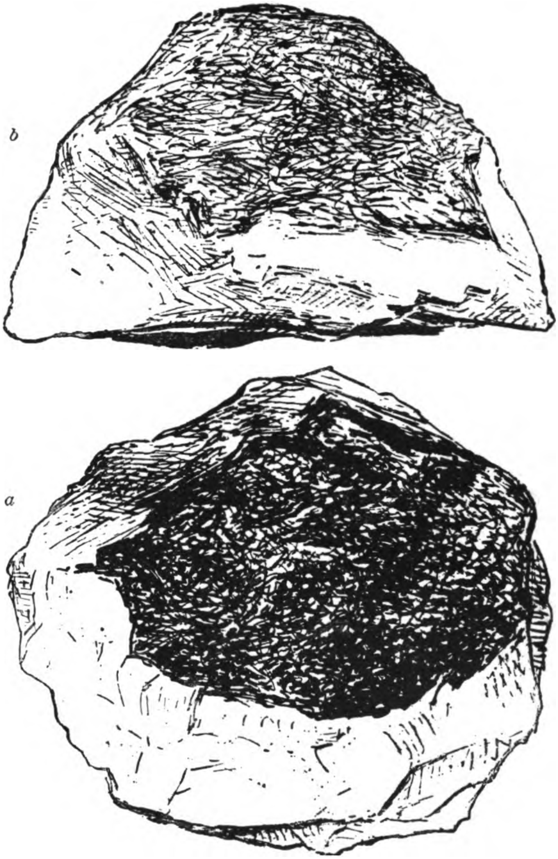

Fig. 74.—Quartz implement, found by Miss F. E. Babbitt, 1878, at Little Falls, Minnesota, in modified drift, fifteen feet below surface: *a*, face view; *b*, profile view. The black represented on the cut is the matrix of the quartz vein (No. 31,323) (Putnam).

But that it was ice-laden water which flooded the banks is shown by the frequent occurrence of large blocks of stone in the deposits, such as could have been transported only

in connection with floating ice. The boulders in the Columbia formation clearly belong to the individual river valleys in which they are found, and doubtless are to be connected with the flooded condition of those valleys when, by means of a northerly subsidence, the gradient of the streams was considerably less than now.

There is some difference of opinion in respect to the extent of this subsidence, and, indeed, respecting the height attained by the Philadelphia brick-clay, or McGee's Columbia deposit. Professor Lewis (whose residence was at Philadelphia, and who had devoted much time to field observations) insisted that the deposit could not be found higher than from 180 to 200 feet above the immediate flood-plain of the river valleys where they occur. But, without entering upon this disputed question, it is sufficient to consider the bearing of the facts that are accepted by all—namely, that towards the close of the Glacial period there was a marked subsidence of the land on the eastern coast of North America, increasing towards the north.

Fully to comprehend the situation, we need to bring before the mind some of the indirect effects of the Glacial period in this region. The most important of these was the necessary projection of subglacial conditions over a considerable belt of territory to the south of that actually reached by glacial ice; so that, while there are no clear indications of the existence of local glaciers in the Appalachian Mountains south of the central part of Pennsylvania, there are many indications of increased snowfall upon the mountains, connected with prolonged winters and with a great increase of spring floods and ice-gorges upon the annual breaking up of winter.

These facts have been stated in detail by Mr. McGee,* from whose report it appears that, on the Potomac at

* Seventh Annual Report of the United States Geological Survey for 1885 and 1886, pp. 537–646.

Washington, the surface of the Columbia deposit is 150 feet above tide, and that the deposit itself contains many boulders, some of which are as much as two or three feet in diameter. These are mingled with the gravel in such a way as to show that they must have been brought down by floating ice from the head-waters of the Potomac when the winters were much more severe than now. That this deposit is properly the work of the river is shown by the entire absence of marine shells.

According to Mr. McGee, also, there is a gradual decrease in the height of these delta terraces of the Columbia period as they recede from the glacial boundary—that at the mouth of the Susquehanna being 245 feet, that of the Potomac 140 feet, that on the Rappahannock 125, that on the James 100, and that on the Roanoke 75; while the size of the transported boulders along the streams also gradually diminishes in the same order. During the Columbia period the Susquehanna River transported boulders fifty times the size now transported, while the Potomac transported them only up to twenty times, the Rappahannock only ten times, the James only five, and the Roanoke only two or three times the size of those now transported. This progressive diminution, both in the extent of the deposit and in the coarseness of the material deposited by these rivers at about the time of the maximum portion of the Glacial period, is what would naturally be expected under the conditions supposed to exist in connection with the great Ice age, and is an important confirmation of the glacial theory

That the period of subsidence and more intense glacial conditions during which the Columbia deposits took place, preceded, by a long interval, the deposition of the gravel terraces at Trenton, N. J., and the analogous deposits in the Mississippi Valley where palæolithic implements have been found, is evident enough. The Trenton gravel was deposited in a recess in the Columbia deposit which had

been previously worn out by the stream. Indeed, in every place where opportunity offers for direct observation the Trenton gravel is seen to be distinctly subsequent to the other. It was not *buried by* the Philadelphia red gravel and brick-clay, but to a limited degree overlies and *buries* it.

The data for measuring the absolute length of time between these two stages of the Glacial period are very indefinite. Mr. McGee, however, supposes that since the Columbia period a sufficient time has elapsed for the falls of the Susquehanna to recede more than twenty miles and for those of the Potomac eighteen miles, and this through a rock which is exceedingly obdurate. But, in channels opening, as these do, freely outward, it is difficult to tell in what epochs the erosion has been principally performed, since there are no buried channels, as in the glaciated area, enabling us to determine whether or not much of the eroding work of the river may have been accomplished in preglacial times.

The lapse of time which, upon the least calculation, separates the Columbia epoch from the Trenton, gives unusual importance to any discovery of palæolithic implements which may be made in the earlier deposits. We are bound, therefore, to consider with special caution the reported discovery of an implement in these deposits at Claymont, Delaware. The discovery was made by Dr. Hilborne T. Cresson, on July 13, 1887, during the progress of an extensive excavation in constructing the Baltimore and Ohio Railroad, nineteen miles south of Philadelphia. The implement was from eight to nine feet below the surface. As there is so much chance for error of judgment respecting the undisturbed condition of the strata, and as there was so little opportunity for Dr. Cresson to verify his conclusion, we may well wait for the cumulative support of other discoveries before building a theory upon it; still, it will be profitable to consider the situation.

Both Mr. McGee and myself have visited the locality with Dr. Cresson, and there can be no doubt that the

implement occurred underneath the Columbia gravel. The line of demarcation is here very sharp between that

a *b*

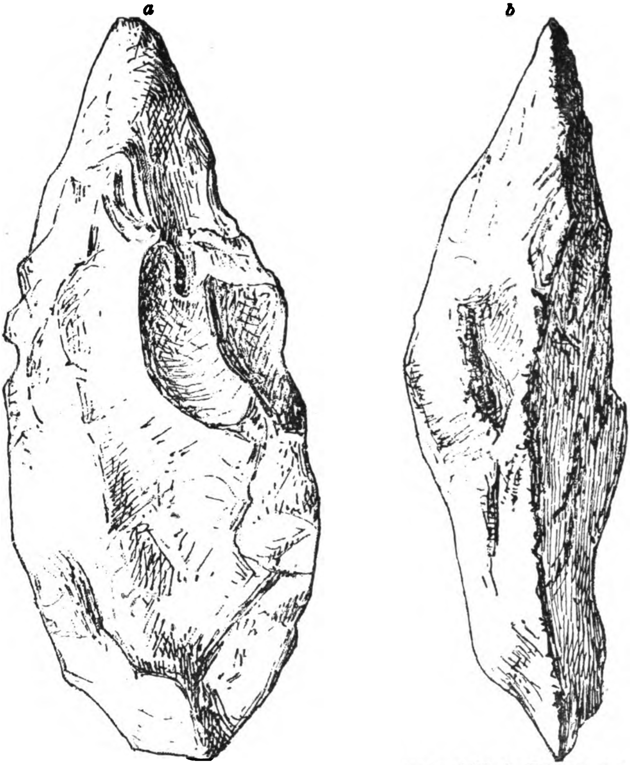

Fig. 75.—Argillite implement, found by H. T. Cresson, 1887, in Baltimore and Ohio Railroad cut, one mile from Claymont, Delaware, in Columbia gravel, eight to nine feet below the overlying clay bed : *a*, face view ; *b*, side view (No. 45,726) (Putnam).

gravel and the decomposed strata of underlying gneiss rock, which appears in our illustration as a light band in the middle of the section exposed. Some large boulders which could have been moved only in connection with floating ice are found in the overlying deposit near by. This excavation is about one mile and a half west of the

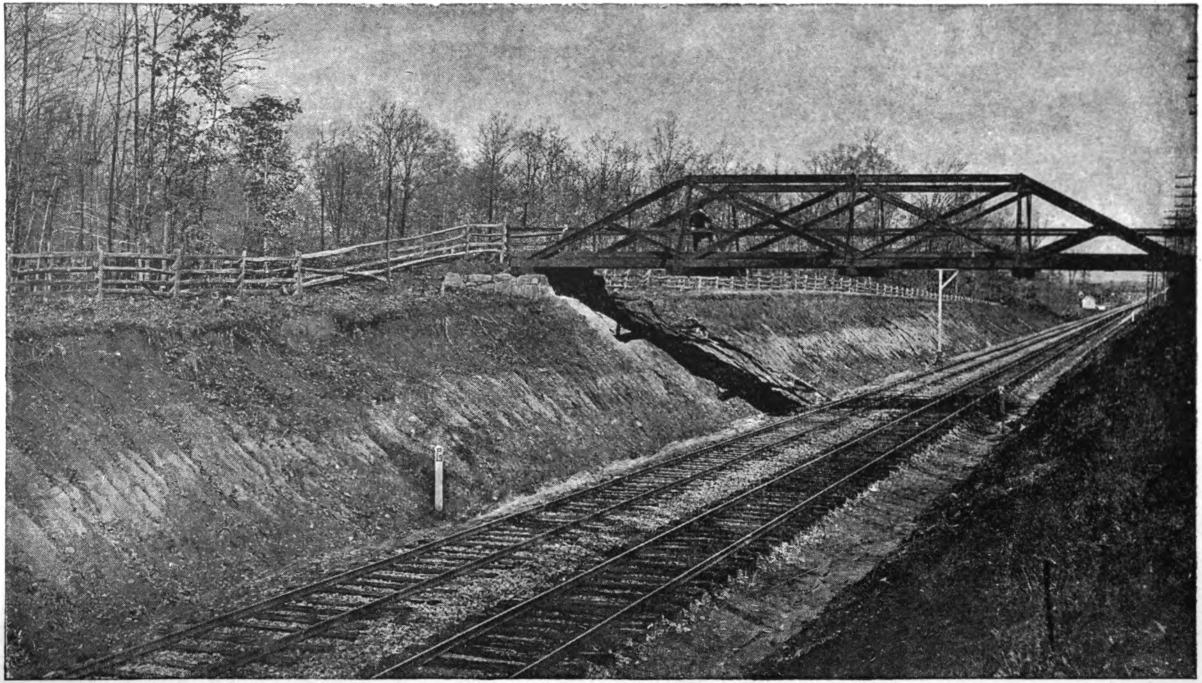

FIG. 76.—General view of section of Baltimore and Ohio cut, near Claymont, Delaware, where Mr. Cresson found palæolithic implements figured in the text (from photograph by Cresson).

Delaware River, and about 150 feet above it, being nearly at the uppermost limit of the Columbia deposit in that vicinity.

The age of these deposits in which implements have been found at Claymont and at Trenton will be referred to again when we come to the specific discussion of the date of the Glacial period. It is sufficient here to bring before our minds clearly, first, the fact that this at Claymont is connected with the river floods accompanying the ice at its time of maximum extension, and when there was a gradually increasing or differential depression of the country to an unknown extent to the northward.

Two radically different theories are presented to account for the deposits variously known as the Columbia gravel and the Philadelphia brick-clay. Mr. McGee, in the monograph above referred to, supposes them to have been deposited during a period of a general subsidence of the coast-line; so that they took place at about tide-level. Mr. Upham, on the other hand, supposes them to have been deposited during the period of general elevation to whose influence he mainly attributes the Glacial period itself. In his view much of the shallow sea-bottom adjoining the present shore off from Delaware and Chesapeake Bays was then a land surface, and the Hudson, the Delaware, and the Susquehanna Rivers, coming down from the still higher elevations of the north, flowed through extensive plains so related to the northern areas of elevation that deposition was occurring in their valleys, owing in part to the flooded condition of the streams, in part to the differential elevation, and in part to the superabundance of silt and other *débris* furnished by the melting ice-sheet in the head-waters of these streams.

The deposits of Trenton gravel occurred much later, at a time when the ice had melted far back towards the head-waters of the Delaware, and after the land had nearly resumed its present relations of level, if indeed

it had not risen northward to a still greater relative height.

As would be expected from the climatic conditions accompanying the Glacial epoch, man's companions in the animal world were very different during the period when the high-level river gravels of America were forming from those with which he is now associated. From the remains actually discovered, either in these gravels or in close proximity to them, we infer that, while the mastodon was the most frequent of the extinct quadrupeds with which man then had to contend in that region, he must have been familiar also with the walrus, the Greenland reindeer, the caribou, the bison, the moose, and the musk ox.

In the Glacial Terraces of Europe.

The existence of glacial man in Europe was first determined in connection with the high-level river gravels already described in the valley of the Somme, situated in Picardy in the northern part of France. Here in 1841 Boucher de Perthes began to discover rudely fashioned stone implements in undisturbed strata of the gravel terraces, whose connection with the Glacial period we have already made clear. But for nearly twenty years his discoveries were ignored by scientific men, although he made persistent efforts to get the facts before them, and published a full account of them with illustrations as early as

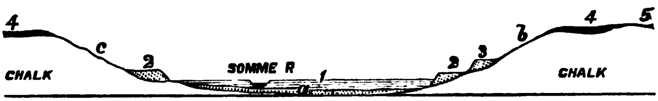

FIG. 77.—Section across valley of the Somme: 1, peat, twenty to thirty feet thick, resting on gravel, *a*; 2, lower-level gravels, with elephant-bones and flint implements, covered with river-loam twenty to forty feet thick; 3, upper-level gravels, with similar fossils covered with loam, in all, thirty feet thick; 4, upland-loam, five to six feet thick; 5, Eocene-Tertiary.

1847. Some suggested fraud on the part of the workmen; others without examination declared that the gravel must

have been disturbed; while others, still, denied altogether the artificial character of the implements.

At length, Dr. ~~Regillout,~~ an eminent physician resid- Rigollot ing at Amiens, about forty miles higher up the Somme than Abbeville, visited Boucher de Perthes, and, upon seeing the similarity between the gravel terraces at Abbeville and Amiens, returned home to look for similar implements in the high-level gravel-pits at St. Acheul, a suburb of Amiens. Almost immediately he discovered flint implements there of the same pattern with those at Abbeville, and in undisturbed strata of the gravel terrace, where it rested on the original chalk formation, at a height of 90 feet above the river. In the course of four years, Dr. ~~Reg-illout~~ Rigollot found several hundred of these implements, and in 1854 published an illustrated report upon the discoveries.

Still the scientific world remained incredulous until the years 1858 and 1859, when Dr. Falconer, Mr. Prestwich, Mr. John Evans, Mr. Flower, Sir Charles Lyell, of England, and MM. Pouchet and Gaudry, of France, visited Abbeville and Amiens, and succeeded in making similar discoveries for themselves. Additional discoveries at St. Acheul have continued up to the present time whenever excavations have gone on at the gravel-pits. Mr. Prestwich estimates that there is an implement to every cubic metre of gravel, and says that he himself has brought away at different times more than two hundred specimens, and that the total number found in this one locality can hardly be under four thousand. "The gravel-beds are on the brow of a hill 97 feet above the river Somme," and besides the relics of man contain numerous fluviatile and land shells together with "teeth and bones of the mammoth, rhinoceros, horse, reindeer, and red deer, but not of the hippopotamus,"* bones of the latter animal being found here only in the gravels of the lower terraces, where they

* Prestwich's Geology, vol. ii, p. 481.

are less than thirty feet above the river, and mark a considerably later stage in the erosion of the valley. While many of the implements found at Amiens seem to have been somewhat worn and rolled, "others are as sharp and fresh as when first made. . . . The bedding of the gravel is extremely irregular and contorted, as though it had been pushed about by a force acting from above; and this, together with the occurrence of blocks of Tertiary sandstone of considerable size, leads to the inference that both are due to the action of river-ice. In the Seine Valley blocks of still larger size, and transported from greater distances, are found in gravels of the same age."

"Flint implements are found under similar conditions in many of the river-valleys of other parts of France, especially in the neighbourhood of Paris; of Mons in Belgium; in Spain, in the neighbourhood of Madrid, in Portugal, in Italy, and in Greece; but they have not been discovered in the drift-beds of Denmark, Sweden, or Russia, nor is there any well-authenticated instance of the occurrence of palæoliths in Germany." *

When once the fact had been established that man was in northern France at the time of the deposition of the high-level gravels of the Somme and the Seine, renewed attention was directed to terraces of similar age in southern England. One of these is that upon which the city of London is built, and which, according to Lyell's description, "extends from above Maidenhead through the metropolis to the sea, a distance from west to east of fifty miles, having a width varying from two to nine miles. Its thickness ranges commonly from five to fifteen feet." †

For a long time geologists had been familiar with the fact that these terraces of the Thames contain the remains of numerous extinct animals, among which are included

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* Prestwich's Geology, vol. ii, pp. 481, 482.

† Antiquity of Man, pp. 154, 155.

the mammoth and a species of rhinoceros. Upon directing special attention to the subject, it was found that, at various intervals, the remains of man, also, had been reported from the same deposits. As long ago as 1715 Mr. Conyers discovered a palæolithic implement, in connection with the skeleton of an elephant, at Black Mary's, near Gray's Inn Lane, London. This implement is preserved in the British Museum, and closely resembles typical specimens from the gravel at Amiens. Other implements of similar character have been found in the valley of the Wey near Guilford, also in the valley of the Darent, near Whitstable in Kent, and between Herne Bay and the Reculvers. While the exact position of these implements in the gravel had not been so positively noted as in the case of those found at Amiens and Abbeville, there can be little doubt that man, in company with the extinct animals mentioned, inhabited the valley of the Thames at a period when its annual floods spread over the whole terrace-plain upon which the main part of London is built.

In the valley of the Ouse, however, near Bedford, the discovery of palæolithic implements in the gravel terraces connected with the Glacial period and in intimate association with bones of the elephant, rhinoceros, hippopotamus, and other extinct animals, has been as fully established as in the valley of the Somme. The discoveries here were first made in the year 1860, by Mr. James Wyatt, in a gravel-pit at Biddenham, two miles northwest of Bedford. Two flint implements were thrown out by workmen in one day from undisturbed strata thirteen feet below the surface, and numerous other specimens have since been found in a similar situation.

The valley of the Ouse is bordered on either side by sections of a superficial blanket of glacial drift containing many transported boulders of considerable size. The valley is here about two miles wide, and ninety feet deep. The gravel deposit, however, in which the implements

were found, is only about thirty feet above the present level of the river, and hence represents the middle period of the work of the river in erosion.

Another locality in England in which similar discoveries have been made, is at Hoxne, about five miles from Diss, in Suffolk County. Like that in the valley of the Thames, however, the implements were found a long time before the significance of the discovery was recognized. Mr. John Frere reported the discovery to the Society of Antiquaries in 1801, and gave some of the implements both to the society and to the British Museum, in whose collections they are still preserved. The implements are of the true palæolithic type, and existed in such abundance, and were so free from signs of wear, that the conclusion seemed probable that a manufactory of them had been uncovered. As many as five or six to the square yard are said to have been found. Indeed, their numbers were so great that the workmen "had emptied baskets of them into the ruts of the adjoining road before becoming aware of their value."

The deposit in which they are found is situated in the valley of Gold Brook, a tributary of the Waveney. The implements occurred about twelve feet below the surface, in fresh-water deposits, filling a hollow eroded in the glacial deposit covering that part of England. This, therefore, is clearly either of post-glacial or of late glacial age.

Still another locality in which similar palæolithic implements were found in undisturbed gravel of this same age in eastern England is Icklingham, in the valley of the Lark, where the situation is quite similar to that already described at Bedford, on the Ouse.

The last place we will stop to mention in England which was visited by palæolithic man, during or soon after the Glacial epoch, is to be found in the vicinity of Southampton. At this time the Isle of Wight was joined to the

mainland, and not improbably England itself to the Continent. The river, then flowing through the depression of the Solent and the Southampton Water, occupied a much higher level than now, leaving terraces along the shore at various places, in which the tools of palæolithic man have been discovered.

Though these are the best authenticated discoveries connecting man with the Glacial period in England, they are by no means the only probable cases. Almost every valley of southern England furnishes evidence of a similar but less demonstrative character.

In Cave Deposits.

The discovery of the remains of man in the high-level river-gravels deposited near the close of the Glacial period led to a revision of the evidence which had from time to time been reported connecting the remains of man with those of various extinct animals in cave deposits both in England and upon the Continent.

The British Isles.

As early as 1826, Rev. J. MacEnery, a Roman Catholic priest residing near Torquay, in Devonshire, England, had made some most remarkable discoveries in a cavern at Kent's Hole, near his home; but, owing to his early death, and to the incredulity of that generation of scientific men, his story was neither credited nor published till 1859. About this time, a new cave having been discovered not far away, at Brixham, the best qualified members of the Royal Society (Lyell, Phillips, Lubbock, Evans, Vivian, Pengelly, Busk, Dawkins, and Sanford) were deputed to see that it was carefully explored. Mr. Pengelly, who had had twenty years' experience in similar explorations, directed and superintended the work. Every portion of the contents was examined with minutest care. Kent's Hole

is "180 to 190 feet above the level of mean tide, and about 70 feet above the bottom of the valley immediately adjacent."* In one chamber the excavation was about sixty feet square. The contents were arranged in the following order:

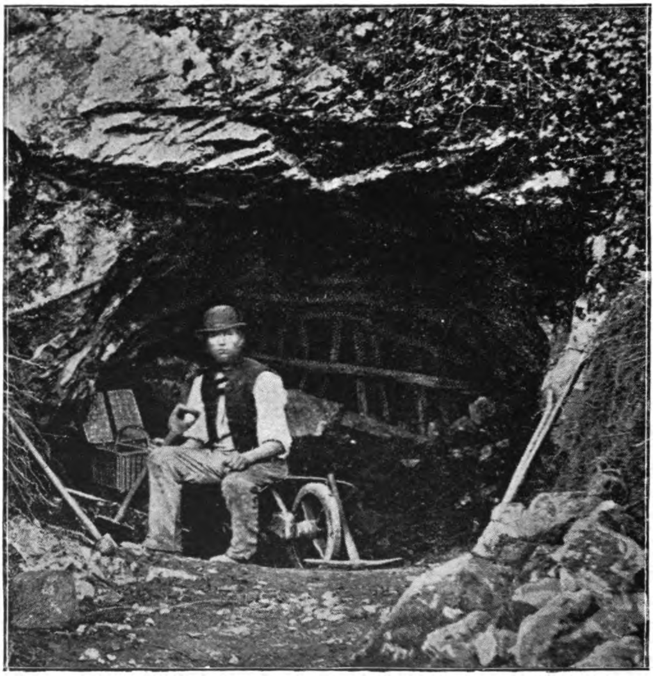

FIG. 78.—Mouth of Kent's Hole.

1. A surface of dark earth a few inches thick, containing Roman pottery, iron and bronze spear-heads, together with polished stone weapons. There were, too, in this stratum bones of cows, goats, and horses, mingled with large quantities of charcoal.

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* Dawkins's Cave-Hunting, p. 325.

2. Below this was a stalagmite floor from one to three feet thick, formed by the dripping of lime-water from the roof.

3. Under this crust of stalagmite was a compact deposit of red earth, from two to thirteen feet thick.* Flint implements of various kinds and charcoal were also found at different depths; also an awl, or piercer; a needle with the eye large enough to admit small pack-thread; and three harpoon-heads made out of bone and deer's horn.

4. Flint implements were also obtained in a conglomerate (breccia) still below this. The fossil bones in this cave belonged to the same species of animals as those discovered in a cave near Wells.

The Brixham cave occurs near the small village of that name, not far from Torquay. The entrance to it is about ninety-five feet above high water. Its deposits, in descending order, are: 1. Stalagmitic floor from six to twelve or fifteen inches in thickness. 2. A thin breccia of limestone fragments cemented together by carbonate of lime. This had accumulated about the mouth, so as to fill up the entrance. 3. A layer of blackish earth about one foot in thickness 4. "A deposit of from two to four feet thick, consisting of clayey loam, mingled with fragments of limestone, from small bits up to rocks weighing a ton. Rounded pebbles of other material were also occasionally met with. 5. Shingle consisting of rounded pebbles largely of foreign material.

All these strata, except the third, contained fossils of some kind, but the fourth was by far the richest repository. Among the bones found are those of the mammoth, the woolly rhinoceros, the horse, the ox, the reindeer, the cave lion, the cave hyena, and the cave bear. Associated with

* Dawkins's Cave-Hunting, p. 326; Lyell's Antiquity of Man, p. 101.

these remains a number of worked flints was found. In one place the bones of an entire leg of a cave bear occurred in such a position as to show that they must have been bound together by the ligaments when they were buried. Immediately below these bones a flint implement was found.*

The hyena's den, at Wookey Hole, near Wells, in Somerset, was carefully explored by Professor Boyd Dawkins, who stood by and examined every shovelful of material as it was thrown out.

This cave alone yielded 35 specimens of palæolithic art, 467 jaws and teeth of the cave hyena, 15 of the cave lion, 27 of the cave bear, 11 of the grizzly bear, 11 of the brown bear, 7 of the wolf, 8 of the fox, 30 of the mammoth, 233 of the woolly rhinoceros, 401 of the horse, 16 of the wild ox, 30 of the bison, 35 of the Irish elk, and 30 of the reindeer (jaws and teeth only).

In Derbyshire numerous caves were explored by Professor Dawkins at Cresswell Crags, which, in addition to flint implements and the remains of the animals occurring in the Brixham cave, yielded the bones of the machairodus, an extinct species of tiger or lion which lived during the Tertiary period.

The Victoria cave, near Settle, in west Yorkshire, is the only other one in England which we need to mention. In this there were no remains found which could be positively identified as human, but the animal remains in the lower strata of the cave deposit were so different from those in the upper bed as to indicate the great lapse of time which separated the two. This cave is 1,450 feet above the sea-level, and there were found in the upper strata of the floor, down to a depth of from two to ten feet, many remains of existing animals. Then, for a distance of twelve feet, there occurred a clay deposit, containing no organic re-

* See Pengelly's Reports to the Devonshire Association, 1867.

mains whatever, but some well-scratched boulders. Below this was a third stratum of earth mingled with limestone fragments, at the base of which were numerous remains of the mammoth, rhinoceros, hippopotamus, bison, hyena, etc. One bone occurred which was by some supposed to be human, but by others to have belonged to a bear. This lower stratum is, without much doubt, preglacial, and the thickness of the deposit intervening between it and the upper fossiliferous bed is taken by some to indicate the great lapse of time separating the period of the mammoth and rhinoceros in England from the modern age. The scratched boulders in the middle stratum of laminated clay, would indicate certainly that the material found its way into the cave during the Glacial epoch, when ice filled the whole valley of the Ribble, which flows past the foot of the hill, and whose bed is 900 feet below the mouth of the cave.

In North Wales the Vale of Clwyd contains numerous caves which were occupied by hyenas in preglacial times, and with their bones are associated those of the mammoth, the rhinoceros, the hippopotamus, the cave lion, the cave bear, and various other animals. Flint implements also were found in the cave at Cae Gwyn, near the village of Tremeirchon, on the eastern side of the valley, opposite Cefn, and about four miles distant. We have already given an illustration of the Cefn cave (see page 148). It will be observed that this valley of the Clwyd opens to the north, and has a pretty rapid descent to the sea from the Welsh mountains, and was in position to be obstructed by the Irish Sea glacier, so as to have been occupied at times by one of the characteristic marginal lakes of the Glacial period. It is evident also that the northern ice prevailed over the Welsh ice for a considerable portion of the lower part of the valley; for northern drift is the superficial deposit upon the hills on the sides of the valley up to a height of over 500 feet. From the investigations of Mr.

C. E. De Rance, F. G. S.,* it is equally clear also that the northern drift, which until lately sealed up the entrance of the cave, was subsequent to its occupation by man, and this was the opinion formed by Sir Archibald Geikie, Director General of the Geological Survey of the United Kingdom, as the result of special investigations which he made of the matter.†

From the caves in the Vale of Clwyd as many as 400 teeth of rhinoceros, 500 of horse, 180 of hyena, and 15 of mammoth have been taken. A section of the cave deposits in the cave at Cae Gwyn is as follows:

"Below the soil for about eight feet a tolerably stiff boulder-clay, containing many ice-scratched boulders and narrow bands and pockets of sand. Below this about seven feet of gravel and sand, with here and there bands of red clay, having also many ice-scratched boulders. The next deposit was a laminated brown clay, and under this was found the bone-earth, a brown, sandy clay with small pebbles and with angular fragments of limestone, stalagmites, and stalactites. During the excavations it became clear that the bones had been greatly disturbed by water action; that the stalagmite floor, in parts more than a foot in thickness, and massive stalactites, had also been broken and thrown about in all positions; and that these had been covered afterwards by clays and sand containing foreign pebbles. This seemed to prove that the caverns, now 400 feet above ordnance datum, must have been submerged subsequently to their occupation by the animals and by man. In Dr. Hicks's opinion, the contents of the cavern must have been disturbed by marine action during the great submergence in mid-glacial times, and afterwards

* Proceedings of the Yorkshire Geological Society for 1888, pp. 1–20.

† See De Rance, as above, p. 17; and article by H. Hicks, in Quarterly Journal of Geological Society, vol. xlii, p. 3; Geological Magazine, May, 1885, p. 510.

covered by marine sands and by an upper boulder-clay, identical in character with that found at many points in the Vale of Clwyd. The paleontological evidence suggests that the deposits in question are not preglacial, but may be equivalent to the Pleistocene deposits of our river-valleys." *

If the views of Professor Lewis and Mr. Kendall are correct concerning the unity of the Glacial period in England, the shelly and sandy deposits connected with these Clwydian caves at an elevation of 400 feet or more would be explained in connection with the marginal lakes which must have occupied the valley during both the advance and the retreat of the ice-front; the shells having been carried up from the sea-bottom by the ice-movement, after the manner supposed in the case of those at Macclesfield and Moel Tryfaen. If, therefore, the statements concerning the discovery of flint implements in this Cae Gwyn cave can be relied upon, this is the most direct evidence yet obtained in Europe of man's occupation of the island during the continuance of the Glacial period.

In all these caves it is to be noted that there is a sharp line of demarcation between the strata containing palæolithic implements and those containing only the remains of modern animals. Palæolithic implements are confined to the lower strata, which in some of the caves are separated from the upper by a continuous bed of stalagmite, to which reference will be made when discussing the chronology of the Glacial period. The remains of extinct animals also are confined to the lower beds.

The caves which we have been considering in England are all in limestone strata, and have been formed by streams of water which have enlarged some natural fissures both by mechanical action in wearing away the rocks, and by chemical action in dissolving them.

* H. B. Woodward's Geology of England and Wales, pp. 543, 544.

Through the lowering of the main line of drainage, caverns with a dry floor are at length left, offering shelter and protection both to man and beast. Oftentimes, but not always, some idea of the age of these caverns may be obtained by observing the depth to which the main channel of drainage to which they were tributary has been lowered since their formation. But to this subject also we will return when we come specifically to discuss the chronological question.

The Continent.

Systematic explorations in the caves of Belgium were begun in 1833 by Dr. Schmerling, in the valley of the Meuse, near his residence in Liége. The Meuse is here bordered by limestone precipices 200 or more feet in height. Opening out from these rocky walls are the entrances to the numerous caverns which have rendered the region so famous. To get access to the most important of these, Dr. Schmerling had to let himself down over a precipice by a rope tied to a tree, and then to creep along on all-fours through intricate channels to reach the larger chambers which it was his object to explore. In the cave at Engis, on the left bank of the Meuse, about eight miles above Liége, he found a human skull deeply buried in breccia in company with many bones of the extinct animals previously stated to have been associated with man during the Glacial period. This so-called "Engis skull" was by no means apelike in its character, but closely re-

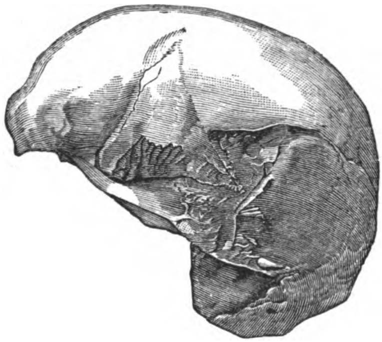

Fig. 79.—Engis skull, reduced (after Lyell.)

sembled that of the average Caucasian man. But this established the association upon the Continent of man with some of the extinct animals of the Glacial period.

The vicinity of Liége has also furnished us another cavern whose contents are of the highest importance, ranking indeed as perhaps the most significant single discovery yet made. The cave referred to is on the property of the Count of Beauffort, in the commune of Spy, in the province of Namur in Belgium. For the facts relating to it we are indebted to Messrs. Lohest and Fraipont, the former Professor of Geology and the latter of Anatomy in the University of Liége. The exploration of the cave was made in 1886, and the full report with illustrations published in the following year in Archives de Biologie.* The significance of this discovery is enhanced by the light it sheds upon and the confirmation it brings to the famous Neanderthal skull and others of similar character, which for a long time had been subjects of vigorous discussion. Before describing it, therefore, we will give a brief account of the previous discoveries.

The famous Neanderthal skull was brought to light in 1857 by workmen in a limestone-quarry, near Düsseldorf, in the valley of the Neander, a small tributary to the Rhine. By these workmen a cavern was opened upon the southern side of the winding ravine, about sixty feet above the stream and one hundred feet below the top of the cliff. The skull attracted much attention from its supposed possession of many apelike characteristics; indeed, it was represented by some to be a real intermediate link between man and the anthropoid apes. The accompanying cut enables one to compare the outline of the Neanderthal skull with that of a chimpanzee on the one hand and of the highly developed European on the other. The apelike peculiarities of this skull appear in its vertical depres-

* See pp. 587, 757.

sion, in the enormous thickness of the bony ridges just above the eyes, and in the gradual slope of the back part of the head, together with some other characteristics which can only be described in technical language; so that it was pronounced by the highest authorities the most apelike of human crania which had yet been discovered. Unfortunately, the jaw was not found. The capacity of the skull, however, was seventy-five cubic inches, which is far above that of the highest of the apes, being indeed equal to the average capacity of Polynesian and Hottentot skulls.* Huxley well remarks that "so large a mass of brain as this would alone suggest that the pithecoid tendencies indicated by this skull did not extend deep into the organization."

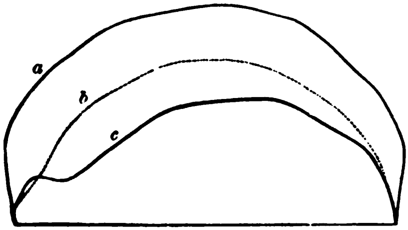

FIG. 80.—Comparison of forms of skulls: *a*, European; *b*, the Neanderthal man; *c*, a chimpanzee (after Lyell).

Upon extending inquiries, it was found that the Neanderthal type of skull is one which still has representatives in all nations; so that it is unsafe to infer that the individual was a representative of all the individuals living in his time. The skull of Bruce, the celebrated Scotch hero, was a close reproduction of the Neanderthal type; while, according to Quatrefages,† the skull of the Bishop of Toul in the fourth century "even exaggerates some of the most striking features of the Neanderthal cranium. The forehead is still more receding, the vault more depressed, and the head so long that the cephalic index is 69·41."

The discovery of Messrs. Fraipont and Lohest adds

* Huxley's Man's Place in Nature, p. 181.

† Human Species, p. 310.

much to our definite knowledge of the Neanderthal type of man, since the Belgic specimens are far more complete than any others heretofore found, there being in their collection two skulls, together with the jawbones and most of the other parts of the frame. In this case also there is no suspicion that the deposits had been disturbed, so as to admit

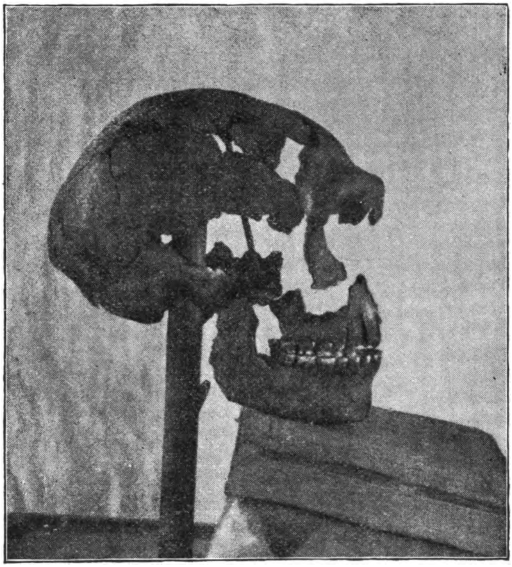

FIG. 81.—Skull of the Man of Spy. (From photograph.)

any intrusion of human relics into the company of relics of an earlier age. According to M. Lohest, there were three distinct ossiferous beds, separated by layers of stalagmite. All the ossiferous beds contained the remains of the mammoth, but in the upper stratum they were few, and probably intrusive. The implements found in this were also of a more modern type. In the second stratum from the top numerous hearths were found with burnt wood and ashes, together with the bones of the rhinoceros, the

horse, the mammoth, the cave-bear, and the cave-hyena, all of which were abundant, while there were also specimens of the Irish elk, the reindeer, the bison, the cave-lion, and several other species. In this layer also there were numerous implements of ivory, together with ornaments and some faint indications of carving upon the rib of a mammoth, besides a few fragments of pottery.

It was in the third, or lowest, of these beds that the skeletons were found. Here they were associated with abundant remains of the rhinoceros, the horse, the bison, the mastodon, the cave-hyena, and a few other extinct species. Flint implements also, of the "Mousterien" pattern (which, according to the opinion of the French archæologists, is characteristic of later palæolithic times), were abundant. Neither of the skeletons was complete, but they were sufficiently so to give an adequate idea of the type to which they belong, and one of the skulls is nearly perfect. According to M. Fraipont, "one of these skulls is apparently that of an old woman, the other that of a middle-aged man. They are both very thick; the former is clearly dolichocephalic (long-headed, index 70), the other less so. Both have very prominent eyebrows and large orbits, with low, retreating foreheads, excessively so in the woman. The lower jaws are heavy. The older has almost no projecting chin. The teeth are large, and the last molar is as large as the others. These points are characteristic of an inferior and the oldest-known race. The bones indicate, like those of the Neanderthal and Naulette specimens, small, square-shouldered individuals." They were "powerfully built, with strong, curiously curved thigh-bones, the lower ends of which are so fashioned that they must have walked with a bend at the knees." *

* Huxley, Nineteenth Century, vol. xxviii (November, 1890), p. 774.

Other crania from different ancient burial-places in Europe seem to warrant the inference that this type of man was the prevalent one during the early part of the Palæolithic age. As long ago as 1700 a skull of this type was exhumed in Canstadt, a village in the neighbourhood of Stuttgart, in Würtemberg. This was found in coexistence with the extinct animals whose bones we have described as so often appearing in the high-level river-gravel of the Glacial age. But the importance of the discovery at Canstadt was not appreciated until about the middle of the present century. From the priority of the discovery, and of the discussion among German anthropologists concerning it, it has been thought proper, however, by some to give the name of this village to the race and call it the "Canstadt race." But, whatever name prevails, it is important in our reading to keep in mind that the man of Canstadt, the man of Neanderthal, and the man of Spy are identical in type, and probably in age. Similar discoveries have been made in various other places. Among these are a lower jaw of the same type discovered in 1865 by M. Dupont, at Naulette, in the valley of the Lesse, in Belgium, and associated with the remains of extinct animals; a jawbone found in a grotto at Arcy; a fragment of a skull found in 1865 by Faudel, in the loess of Eguisheim, near Colmar; a skull at Olmo, discovered in 1863, in a compact clayey deposit forty-five feet below the surface; and a skull discovered in 1884 at Marcilly.

M. Dupont has brought to light much additional testimony to glacial man from other caves in different parts of Belgium. In all he has explored as many as sixty. Three of these, in the valley of the Montaigle, situated about one hundred feet above the river, contained both remains of man and many bones of the mammoth and other associated animals, which had evidently been brought in for food.

In the hilly parts of Germany, also, and in Hungary,

and even in the Ural Mountains in Russia, and in one of the provinces of Siberia, the remains of the rhinoceros, and most of the other animals associated with man in glacial times, have been found in the cave deposits which have been examined. Though it can not be directly proved that these animals were associated with man in any of these places, still it is interesting to see how widespread the animals were in northern Europe and Asia during the Glacial period.

Some northern animals, also, spread at this time into southern Europe—remains of the reindeer having been discovered on the south slope of the Pyrenees, but the remains of the mammoth, the woolly rhinoceros, and the musk ox, have not been found so far south.

African species of the elephant, however, seem at one time to have had free range throughout Spain, and the hippopotamus roamed in vast herds over the valleys of Sicily, while several species of pygmy elephants seem to be peculiar to the island of Malta.

In the case of all the cave deposits referred to (with possibly the exception of those of Victoria, England, and Cae Gwyn, Wales), the evidence of man's existence during the Glacial period is inferential, and consists largely in the fact that he was associated with various extinct animals which did not long survive that period, or with animals that have since retired from Europe to their natural habitat in mountain-heights or high latitudes. The men whose remains are found in the high-level river-drift, and in the caverns described, were evidently not in possession of domestic animals, as their bones are conspicuous for their absence in all these places. The horse, which would seem to be an exception, was doubtless used for food, and not for service.

If we were writing upon the general subject of the antiquity and development of the human race, we should speak here in detail of several other caves and rock shel-

ters in France and southern Europe, where remains of man belonging to an earlier period have been found. We should mention the rock shelter of Cro-Magnon in the valley of Vezère, as well as that of Mentone, where entire human skeletons were found. But it is doubtful if these and other remains from caves which might be mentioned belong in any proper sense to the Glacial period. The same remarks should be made also with reference to the lake-dwellings in Switzerland, of which so much has been written in late years. All these belong to a much later age than the river-drift man of whom we are speaking, and of whom we have such abundant evidence both in Europe and in America.

Extinct Animals associated with Man during the Glacial Period.

This is the proper place in which to speak more fully of the extinct animals which accompanied man in his earliest occupation of Europe and America, and whose

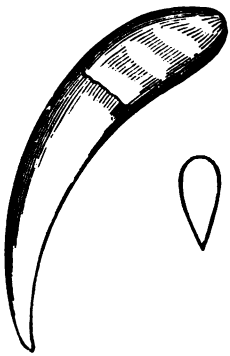

Fig. 82.

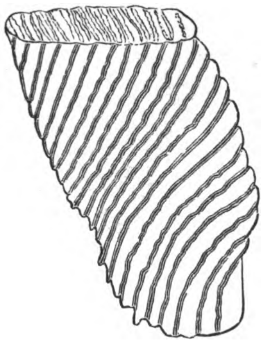

Fig. 83.

Fig. 82.—Tooth of Machairodus neogæus, × $\frac{1}{3}$ (drawn from a cast).
Fig. 83.—Perfect tooth of an Elephas, found in Stanislaus County, California, $\frac{1}{3}$ natural size.

remains are so abundant in the river-drift gravel and in the caves of England, in connection with the relics of man. Among these animals are

The LION, which is now confined to Africa and the warmer portions of Asia. But in glacial times a large species of this genus ranged over Europe from Sicily to central England.

The saber-toothed TIGER, with tusks ten inches long (*Machairodus latidens*), is now extinct. This species was in existence during the latter part of the Tertiary period, but continued on until after man's appearance in the Glacial period. The presence of this animal would seem to indicate a warm climate.

The LEOPARD (*Felis pardus*) is now confined to Africa and southern Asia, and the larger islands adjoining; but during man's occupation of Europe in the Glacial epoch he was evidently haunted at every step by this animal; for his bones are found as far north in England as palæolithic man is known to have ranged.

The HYENA. Two species of this animal are found in the bone-caves of Europe. During the Glacial epoch

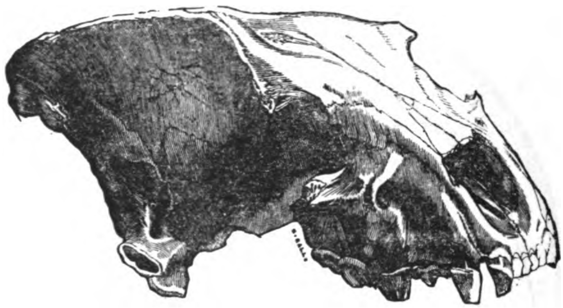

FIG. 84.—Skull of Hyena spelæa, × ¼.

they ranged as far up as northern England, but they are now limited to Africa and southwestern Asia.

The ELEPHANT is represented in the Preglacial and Glacial epochs by several species, some of which ranged as far north as Siberia. The African elephant is not now found north of the Pyrenees and the Alps.* A species of

* i.e., his remains.

dwarf elephant, but four or five feet in height, has already been referred to as having occupied Malta and Sicily; and still another species has been found in Malta, whose average height was less than three feet. An extinct species (*Elephas antiquus*), whose remains are found in the river-drift and in the lower strata of sediment in many caverns as far north as Yorkshire, England, was of unusual size, and during the Glacial period was found on both sides of the Mediterranean. But the species most frequently met with in palæolithic times was the mammoth (*Elephas primigenius*). This animal, now extinct, accompanied man in nearly every portion both of Europe and North America, and lingered far down into post-glacial times before becoming extinct. This animal was nearly

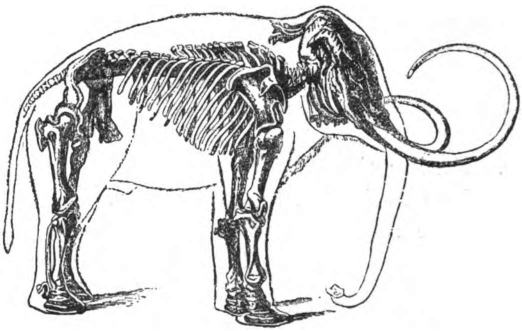

FIG. 85.—Celebrated skeleton of mammoth, in St. Petersburg museum.

twice the weight of the modern elephant, and one third taller. Occasionally his tusks were more than twelve feet long, and curved upward in a circle. It is the carcasses of this animal which have been found in the frozen soil of Siberia and Alaska. It had a thick covering of long, black hair, with a dense matting of reddish wool at the roots. During the Glacial period these animals must have roamed in vast herds over the plains of northern

France and southern England, and the northern half of North America.

The HIPPOPOTAMUS is at present a familiar animal in the larger rivers of Africa, but is not now found in

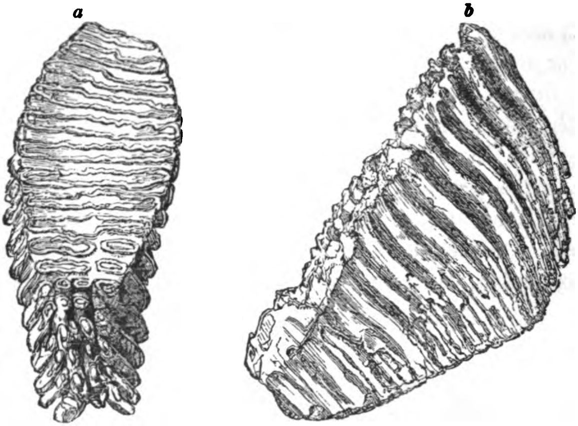

FIG. 86.—Molar tooth of mammoth (Elephas primigenius): *a*, grinding surface; *b*, side view.

Europe. During the Glacial period, however, he ranged as far north as Yorkshire, England, and his remains were found in close association with those of man, both in Europe and on the Pacific coast in America. Twenty tons of their bones have been taken from a single cave in Sicily.*

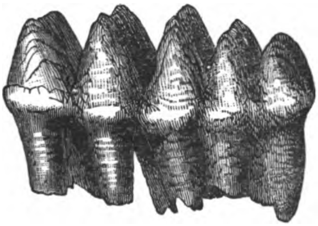

FIG. 87.—Tooth of Mastodon Americanus.

The mammoth and the rhinoceros we know to have been adapted to cold climates by the possession of long hair and thick fur, but the hippopotamus by its love for water would seem to be precluded from the possession of this protective cov-

* Prestwich's Geology, vol. ii, p. 508.

ering. It is suggested, however, by Sir William Dawson, that he may have been adapted to arctic climates by a fatty covering, as the walrus is at the present time. A difficulty in accounting for many of the remains of the hippopotamus in some of the English caverns is that they are so far away from present or possible water-courses. But it would seem that due credit has not been ordinarily given to the migratory instincts of the animal. In southern Africa they are known to "travel speedily for miles over land from one pool of a dried-up river to another; but it is by water that their powers of locomotion are surpassingly great, not only in rivers, but in the sea. . . . The geologist, therefore, may freely speculate on the time when herds of hippopotami issued from North African rivers, such as the Nile, and swam northward in summer along the coasts of the Mediterranean, or even occasionally visited islands near the shore. Here and there they may have landed to graze or browse, tarrying awhile, and afterwards continuing their course northward. Others may have swum in a few summer days from rivers in the south of Spain or France to the Somme, Thames, or Severn, making timely retreat to the south before the snow and ice set in." *

The MASTODON (*Mastodon Americanus*), (Fig. 88), "is probably the largest land mammal known, unless we except the *Dinotherium.* It was twelve to thirteen feet high, and, including the tusks, twenty-four to twenty-five feet long. It differed from the elephant chiefly in the character of its teeth. The difference is seen in Figs. 86 and 87. The elephant's tooth given above (Fig. 86) is sixteen inches long, and the grinding surface eight inches by four."

The mastodon, together with the mammoth, made their appearance about the middle of the Miocene epoch.

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* Lyell, Antiquity of Man, p. 180,

At the close of the Tertiary period the mastodon became extinct on the Eastern Continent, but continued in North America to be a companion of man well on toward the close of the Glacial period. Many perfect skeletons have

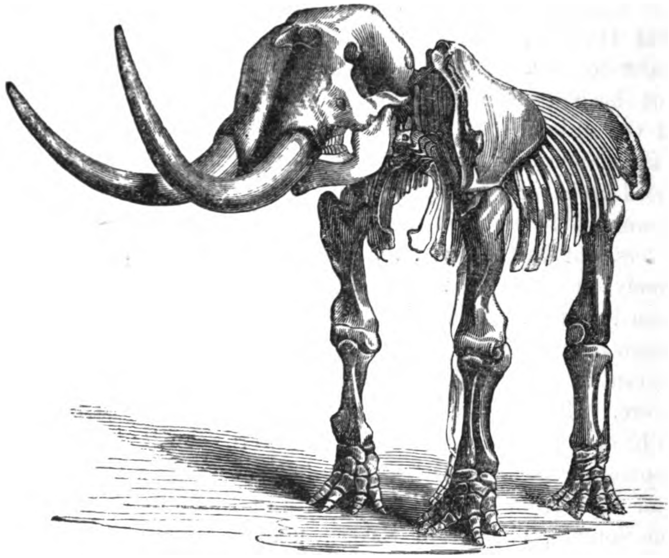

FIG. 88.—Mastodon Americanus (after Owen).

been found in the deposits of this period in North America. "One magnificent specimen was found in a marsh near Newburg, New York, with its legs bent under the body, and the head thrown up, evidently in the very position in which it mired. The teeth were still filled with the half-chewed remnants of its food, which consisted of twigs of spruce, fir, and other trees; and within the ribs, in the place where the stomach had been, a large quantity of similar material was found." *

The RHINOCEROS is now confined to Africa and south-

* Le Conte's Geology (edition of 1891), p. 582.

ern Asia; but the remains of four species have been found in America, Europe, and northern Asia, in deposits of the Glacial period. In company with that of the mammoth, already spoken of, a carcass of the woolly rhinoceros was found in 1771 in the frozen soil of northern Siberia. The bones of other species have been found as far north as Yorkshire, England. In the valley of the Somme there was found "the whole hind limb of a rhinoceros, the bones of which were still in their true relative position. They must have been joined together by ligaments and even surrounded by muscles at the time of their interment." An entire skeleton was found near by. The gravel terrace in which these occurred is about forty feet above the floor of the valley, and must have been formed subse-

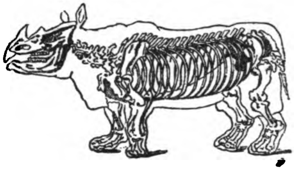

FIG. 89.—Skeleton of Rhinoceros tichorhinus.

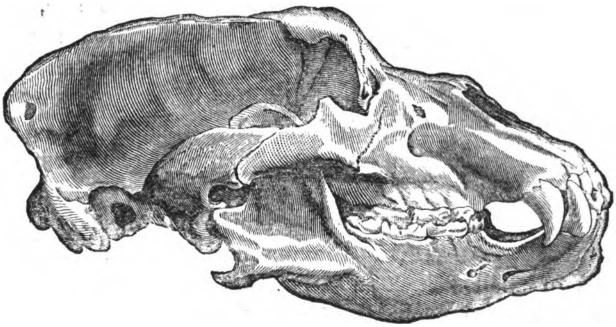

FIG. 90—Skull of cave-bear (Ursus spelæus), × ⅛.

quent to some of the strata which contained the remains of human art. In America the bones are found in the gold-bearing gravels of California, in connection with human remains.

The BEAR was represented in Europe in palæolithic times by three species, of which only one exists there at

the present time. But during the Glacial period the grizzly bear, now confined to the western part of America, and the extinct cave-bear were companions, or enemies as the case may be, of man throughout Europe. The cave-bear was of large size, and his bones occur almost everywhere in the lower strata of sediment in the caves of England.

The great IRISH ELK, or deer, is now extinct, though it is supposed by some to have lingered until historic times. Its remains are found widely distributed over middle Europe in deposits of palæolithic age.

FIG. 91.—Skeleton of the Irish elk (Cervus megaceros).

The HORSE was also, as we have seen, a very constant associate of man in middle Europe during the Palæolithic age, but probably not as a domesticated animal. The evidence is pretty conclusive that he was prized chiefly for food. About some of the caves in France such immense quantities of their bones are found that they can be accounted for best as refuse-heaps into which the useless bones had been thrown after their feasts, after the manner of the disposal of shells of shell-fish. In America the horses associated with man were probably of a species now extinct. The skull of one (*Equus excelsus*) recently found in Texas, in Pleistocene deposits, associated with human implements, is, according to Cope, intermediate in character between the horse and quagga.* The frontal bone was crushed in in a manner to suggest that it had been knocked

* American Naturalist, vol. xxv (October, 1891), p. 912.

in the head with a stone hammer, such as was found in the same bed. Possibly, therefore, man's love of horse-flesh may have been an important element in securing the extinction of the species in America.

Besides these animals there were associated with man at this time the Musk Sheep and the Reindeer, both now confined to the regions of the far north, but during the Glacial period ranging into southern France, and mingling their bones with those both of man and of the southern species already enumerated.

The Wolverine, the Arctic Fox, the Marmot, the Lemming—all now confined to the far north—at that time mingled on the plains of central Europe with the species mentioned as belonging now to Africa and south-

Fig. 92.—Musk-sheep (Ovibos moschatius).

ern Asia. The Ibex, also, and the Snowy Vole and Chamois descended to the plains from their mountain-heights, and joined in the strange companionship of animals from the north and from the south.

Besides these extremes there were associated with man during the Glacial period numerous representatives of the temperate group of existing animals, such as the bison, the horse, the stag, the beaver, the hare, the rabbit, the

* or to Alpine regions,

otter, the weasel, the wild-cat, the fox, the wolf, the wild boar, and the brown bear.

To account for this strange intermingling of arctic and torrid species of animals, especially in Europe, during man's occupancy of the region in glacial times, various theories have been resorted to, but none of them can be said to be altogether satisfactory. One hypothesis is that the bones of these diverse animals became mingled by reason of the great range of the annual migration of the species. The reindeer, for example, still performs extensive annual migrations. In summer it ventures far out upon the *tundras* of North America and Siberia to feed upon the abundant vegetation that springs up like magic under the influence of the long days of sunshine; while, as winter approaches, it returns to the forests of the interior. Or in other places this animal and his associates, like birds of passage, move northward in summer to escape the heat, and southward in the winter to escape the extreme cold. Many of the other animals also are more or less migratory in their habits.

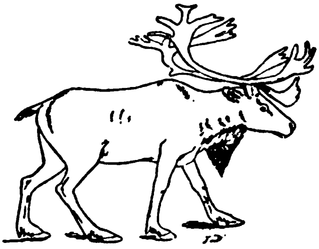

FIG. 93.—Reindeer.

Thus it is thought that during the Glacial period, when man occupied northern France and southern England, the reindeer, the musk sheep, the arctic fox, and perhaps the hippopotamus and some other animals, annually vibrated between northern England and southern France, a slight elevation of the region furnishing a land passage from England to the continent; while the chamois and other Alpine species vibrated as regularly between the valleys in winter and the mountain-heights in summer. The habits of these species are such that it is not difficult to see how in their case this migration could have taken place.

Professor Boyd Dawkins attempts to reduce the difficulty by supposing that the Glacial epoch was marked by the occurrence of minor periods of climatic variation, during which, in comparatively short periods, the isothermal lines vibrated from north to south, and *vice versa*. In this view the southern species gradually crowded upon the northern during the periods of climatic amelioration, until they reached their limit in central England, and then in turn, as the climate became more rigorous, slowly retreated before the pressure of their northern competitors. Meanwhile the hyena sallied forth from his various caves, over this region, at one time of the year to feed upon the reindeer, and at another time of the year upon the flesh of the hippopotamus, in both cases dragging their bones with him to his sheltered retreat in the limestone caverns * which he shared at intervals with palæolithic man.

The theory of Mr. James Geikie is that the period, while one of great precipitation, was characterised by a climate of comparatively even temperature, in which there was not so great a difference as now between the winters and the summers, the winters not being so cold and the summers not so hot as at present. This is substantially the condition of things in southern Alaska at the present time, where extensive glaciers come down to the sea-level, even though the thermometer at Sitka rarely goes below zero (Fahrenheit). It is, therefore, easy to conceive that if there were extensive plains bordering the Alaskan archipelago, so as to furnish ranging grounds for more southern species, the animals of the north and the animals of the south might partially occupy the same belt of territory, and their bones become mingled in the same river deposits.

In order to clear the way for either of these hypotheses to account for the mingling of arctic and torrid species

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* Early Man in Britain, p. 114.

characteristic of the period under consideration in Europe, we must probably suppose such an elevation of the region to the south as to afford land connection between Europe and Africa. This would be furnished by only a moderate amount of elevation across the Strait of Gibraltar and from the south of Italy to the opposite shore in Africa; and there are many indications, in the distribution of species, of the existence in late geological times of such connection.

It should also be observed that the present capacities and habits of species are not a certain criterion of their past habits and capacities. As already remarked, both the rhinoceros and the mammoth of glacial times were probably furnished with a woolly protection, which enabled them to endure more cold than their present descendants could do, while the elephant is even now known to be able to endure the rigors of the climate at great elevations upon the Himalaya Mountains. We can easily imagine these species to have been adjusted to quite different climatic conditions from those which now seem necessary to their existence. In the case of the hippopotamus, also, it is quite possible, as already suggested, that it is more inclined to migration than is generally supposed.

Geikie's theory of the prevalence of an equable climate during a portion of the Glacial period in Europe is thought to be further sustained by the character of the vegetation which then covered the region, as well as by the remains of the mollusks which occupied the waters. Then "temperate and southern species like the ash, the poplar, the sycamore, the fig-tree, the Judas-tree, the laurel, etc., overspread all the low ground of France, as far north at least as Paris. . . . It was under such conditions," continues Geikie, "that the elephants, rhinoceroses, and hippopotamuses, and the vast herds of temperate cervine and bovine species ranged over Europe, from the shores of the Mediterranean up to the latitude of York-

shire, and probably even farther north still; and from the borders of Asia to the Western Ocean. Despite the presence of numerous fierce carnivora—lions, hyenas, tigers, and others—Europe at that time, with its shady forests, its laurel-margined streams, its broad and deep-flowing rivers, a country in every way suited to the needs of a race of hunters and fishers—must have been no unpleasant habitation for palæolithic man.

"This, however, is only one side of the picture. There was a time when the climate of Pleistocene Europe presented the strongest contrast to those genial conditions—a time when the dwarf birch of the Scottish Highlands, and the arctic willow, with their northern congeners, grew upon the low grounds of middle Europe. Arctic animals, such as the musk sheep and the reindeer, lived then, all the year round, in the south of France; the mammoth ranged into Spain and Italy; the glutton descended to the shores of the Mediterranean; the marmot came down to the low grounds at the foot of the Apennines; and the lagomys inhabited the low-lying maritime districts of Corsica and Sardinia. The land and fresh water shells of many Pleistocene deposits tell a similar tale; boreal, high alpine, and hyperborean forms are characteristic of these accumulations in central Europe; even in the southern regions of our continent the shells testify to a former colder and wetter climate." *

In Mr. Geikie's view these facts indicate two Glacial periods, with an intervening epoch of mild climate. In the opinion of others they are readily explainable by the coming on and departure of a single Ice age, with its various minor episodes.

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* Prehistoric Europe, p. 67.

Earliest Remains of Man on the Pacific Coast of North America.

Most interesting evidence concerning the antiquity of man in America, and his relation to the Glacial period, has come from the Pacific coast. During the height of the mining activity in California, from 1850 to 1860, numerous reports were rife that human remains had been discovered in the gold-bearing gravel upon the flanks of the Sierra Nevada Mountains. These reports did not attract much scientific attention until they came to relate to the gravel deposits found deeply buried beneath a flow

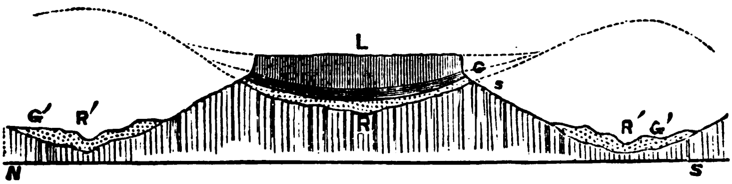

FIG. 94.—Section across Table Mountain, Tuolumne County, California: *L*, lava; *G*, gravel; *S*, slate; *R*, old river-bed; *R'*, present river-bed.

of lava locally known as the Sonora or Tuolumne Table Mountain. This lava issued from a vent near the summit of the mountain-range, and flowed down the valley of the Stanislaus River for a distance of fifty or sixty miles, burying everything in the valley beneath it, and compelling the river to seek another channel. The thickness of the lava averages about one hundred feet, and so long a time has elapsed since the eruption that the softer strata on either side of the valley down which it flowed have been worn away to such an extent that the lava now rises nearly everywhere above the general level, and has become a striking feature in the landscape, stretching for many miles as a flat-topped ridge about half a mile in width, and presenting upon the sides a perpendicular face of solid basalt for a considerable distance near the lower end of the flow.

It was under this mountain of lava that the numerous implements and remains of man occurred which were reported to Professor J. D. Whitney when he was conducting the geological survey of California between 1860

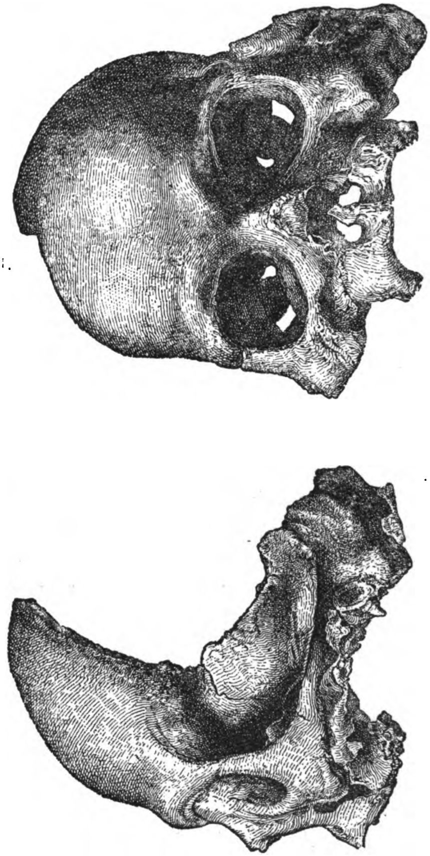

FIG. 95.—Calaveras Skull. (From Whitney.)

and 1870. The implements consisted of stone mortars and pestles, suitable for use in grinding acorns and other coarse articles of food. There were, however, some rude articles of ornament. In one of the mining shafts pene-

trating the gravel underneath Table Mountain, near Sonora, there was reported to have been discovered, in 1857, a human jawbone, one portion of which was sent by responsible parties to the Boston Society of Natural History, and another part to the Philadelphia Academy of Sciences, in whose collections the fragments can now be seen.

Interest reached a still higher pitch when, in 1866, an entire human skull with some other human bones was reported to have been discovered under this same lava deposit, a few miles from Sonora, at Altaville, in Calaveras County, and hence known as the "Calaveras skull." Persistent efforts were made soon after to discredit the genuineness of this discovery. Bret Harte showered upon it the shafts of his ridicule, and various other persons gave currency to the story that the whole report originated in a joke played by the miners upon unsuspecting geologists. These attacks were so successful that many conservative archæologists and men of science have refused to accept the skull as genuine.

Recent events, however, have brought such additional evidence * to the support of this discovery that it would seem unreasonable any longer to refuse to credit the testimony. At the meeting of the Geological Society of America, at Washington, in January, 1891, Mr. George F. Becker, of the United States Geological Survey, who for some years has had charge of investigations relating to the gold-bearing gravels of the Pacific coast, presented the affidavit of Mr. J. H. Neale, a well-known mining engineer of unquestionable character, stating that he had taken a stone mortar and pestle, together with some spear-heads (which through Mr. Becker he presented to the Society), from undisturbed strata of gravel underneath the lava of Table Mountain, near Rawhide Gulch, a few

* See Bulletin Geological Society of America, 1891, pp. 189–200.

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Prof. Put[illegible] seems to prove [illegible] Am. [illegible] pp. 81–109.

[illegible] 1905. p. [illegible]

miles from Sonora. At the same meeting Mr. Becker presented a pestle which Mr. Clarence King, the first director of the United States Geological Survey, took with his own hands out of undisturbed gravel under this same lava deposit, near Tuttletown, a mile or two from the preceding locality mentioned.

I was so fortunate, also, as to be able to report to the Society at the same meeting the discovery, in 1887, of a small stone mortar by Mr. C. McTarnahan, the assistant surveyor of Tuolumne County. This mortar was found by Mr. McTarnahan in the Empire mine, which penetrates the gravel underneath Table Mountain, about three miles from Sonora, and not far from the other localities above mentioned. The place where the mortar was found is about one hundred and seventy-five feet in from the edge of the superincumbent lava, which is here about one hundred feet in thickness. At my request, this mortar was presented by its owner, Mrs. M. J. Darwin, to the Western Reserve Historical Society of Cleveland, Ohio, in whose collection it can now be seen.

These three independent instances, each of them authenticated by the best of evidence, have such cumulative force that probably few men of science will longer stand out against it.

Associated with these discoveries, there is to be mentioned another, which was brought to my notice by Mr. Charles Francis Adams in October, 1889.† This was a miniature clay image of a female form, about one inch and a half in length, and beautifully formed, which was found, in August, 1889, by Mr. M. A. Kurtz, while boring an artesian well at Nampa, Ada County, Idaho. The strata passed through included, near the surface, fifteen feet of lava. Underneath this, alternating beds of clay and

† See Proceedings Boston Society Natural History, January, 1890, and February, 1891.

[illegible] (Univ. of California Publications), [illegible] see his "Records of the Past," vii, [illegible] 185[illegible] '57; "The [illegible] concerning Pre-historic [illegible] in [illegible]

quicksand occurred to a depth of three hundred and twenty feet, where there appeared indications of a former surface soil lying just above the bed-rock, from which the clay image was brought up in the sand-pump.

FIG. 96.—Three views of Nampa image drawn to scale. The middle one is from a photograph.

I devoted the summer of 1890 to a careful study of the lava deposits both in Idaho and in California, with a view to learning their significance with reference to these discoveries. The main facts brought to light by this investigation are that in the Snake River Valley, Idaho, there are not far from twelve thousand square miles of territory covered with a continuous stratum of basaltic lava, extending nearly across the entire diameter of the State from east to west. Nampa, where the miniature image was discovered, is within five miles of the western limit of this lava-flow, and where it had greatly thinned out. The relative age of the lava is shown by its relation to Tertiary beds of shale and sandstone, containing numerous fossils of late Pliocene species. These are overlaid in this vicinity by the lava, thus determining its post-Tertiary character. Examination with reference to the more precise determination of age reveals channels of erosion formed since the lava-flow took place, which, when studied sufficiently, will probably lead to valuable approximate

results. At present I can only say that the amount of erosion since the lava eruptions of western Idaho is not excessive, and very likely may be brought within a period of from ten thousand to twenty thousand years. The enormous erosion in the cañon of the Snake River, near Shoshone Falls, in central Idaho, is doubtless of a much earlier date than that in the Boisé River, near Nampa.

The disturbances created in this part of the valley by the bursting of the barriers between the glacial Lake

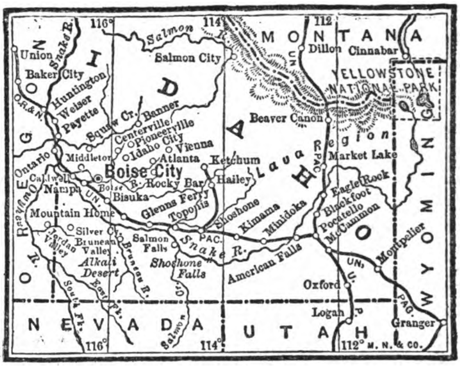

FIG. 97.—Map showing Pocatello, Nampa, and the valley of Snake River.

Bonneville and the Snake River, already described (see above, page 233), have not been worked out. There can be no doubt, however, that interesting results will come to light in connection with the problem; for Pocatello, the point at which the *débâcle* reached the Snake River plain, is about 2,000 feet higher than Nampa, and 350 miles distant, and the water must have poured into the valley faster than the river in its upper portion could have discharged it. By just what channels the mighty current worked down to the lower levels on the western borders of the State it would be most interesting as well as instructive to know.

A study of the situation in Tuolumne and Calaveras

Counties, California, reveals a state of things closely resembling, in important respects, that in western Idaho. At first sight the impression is made that an immense lapse of time must have occurred since the volcanic eruption which furnished the lava of Table Mountain. The Stanislaus River flows in a channel of erosion a thousand feet or more lower than the ancient channel filled by lava, and in two or three places cuts directly across it. An immense amount of time, also, would seem to be required to permit the smaller local streams to have worn away so

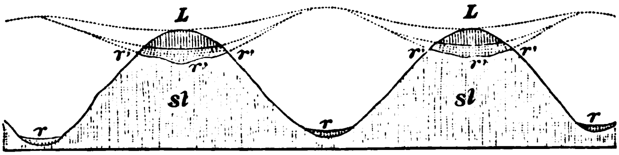

FIG. 98.—Section along the line, north and south: *r' r'*, old river-beds; *r r*, present river-beds; *L*, lava; *sl*, slate.

much of the sides of the ancient valley as to allow the lava deposit now so continuously to rise above the general surface. Still, the question of absolute time cannot be considered separately without much further study. It is by no means certain that, when the lava-stream poured down the mountain, it always followed the lowest depressions; but at certain points it may have been dammed up in its course by its own accumulations so as to be turned off into what was then an ancient abandoned channel.

The forms of animal and vegetable life with which the remains of man under Table Mountain are associated, are, indeed, to a considerable extent, species now extinct in California, and some of them no longer exist anywhere in the world. But a suggestion of Professor Prestwich, in England, made with reference to the extinct forms of life associated with human remains in the glacial deposits in Europe, is revived by Mr. Becker, of the Geological Survey, with reference to the California discoveries; his

inference being, not that man is so extremely ancient in California, but that many of these plants and animals have continued to a more recent date than has ordinarily been supposed.

The connection of these lava-flows on the Pacific coast with the Glacial period is unquestionably close. For some reason which we do not fully understand, the vast accumulation of ice in North America during the Glacial period is correlated with enormous eruptions of lava west of the Rocky Mountains, and, in connection with these events, there took place on the Pacific coast an almost entire change in the plants and animals occupying the region. Mr. Warren Upham is of the opinion that on the Pacific coast they lingered much later than in the region east of the Rocky Mountains. Indeed, it is pretty certain that not many centuries have elapsed since the glacial phenomena of the Sierra Nevada Mountains were much more pronounced than they are at the present time, and it is equally certain that there have been vast eruptions of lava in California within three hundred years.

From these data, therefore, Mr. Becker has real foundation for his suggestion that perhaps in the Glacial period California was a kind of health resort for Pliocene animals, as it is at the present time for man; or, at any rate, that the later date of the accumulations permitted the animals to survive there much longer than in the region east of the Rocky Mountains.

Further discussion of the preceding facts will profitably be deferred until, in the next two chapters, the questions of the cause and date of the Glacial period have been considered.

CHAPTER IX.

THE CAUSE OF THE GLACIAL PERIOD.

In searching for the cause of the Glacial period, it is evident that we must endeavor to find conditions which will secure over the centre of the glaciated area either a great increase of snow-fall or a great decrease in the mean annual temperature, or both of these conditions combined in greater or less degree. As can be seen, both from the nature of the case and from the unglaciated condition of Siberia and northern Alaska, a low degree of temperature is not sufficient to produce permanent ice-fields. If the snow-fall is excessively meagre, even the small amount of heat in an arctic summer will be sufficient to melt it all away.

From the condition of Greenland, however, it appears that a moderate amount of precipitation where it is chiefly in the form of snow may produce enormous glaciers if at the same time the average temperature is low. In south-eastern Alaska, on the other hand, the glaciers are of enormous size, though the mean annual temperature is by no means low, for there the great amount of snow-fall amply compensates for the higher temperature.

Snow stores the cold and keeps it in a definite place. If the air becomes chilled, circulation at once sets in, and the cold air is transferred to warmer regions; but if there is moisture in the air, so that snow forms, the cold becomes locked up, as it were, and falls to the earth.

The amount of cold thus locked up in snow is enor-

mous. To melt one cubic foot of ice requires as much heat as would raise the temperature of a cubic foot of water 176° Fahrenheit. To melt a "layer of ice only one inch and a half thick would require as much heat as would raise a stratum of air eight hundred feet thick from the freezing-point to the tropical heat of 88° Fahrenheit." It is the slowness with which ice melts which enables it to accumulate as it does, both in winter and upon high mountains and in arctic regions. Captain Scoresby relates that when near the north pole the sun would sometimes be so hot as to melt the pitch on the south side of his vessel, while water was freezing on the north side, in the shade, owing to the cooling effect of the masses of ice with which he was surrounded.

Thus it will appear that a change in the direction of the moist winds blowing from the equator towards the poles might produce a Glacial epoch. If snow falls upon the ocean it cools the water, but through the currents, everywhere visible in the sea, the temperature in the water in the different parts soon becomes equalized. If, however, the snow falls upon the land, it must be melted by the direct action of the sun and wind upon the spot where it is. If the heat furnished by these agencies is not sufficient to do it year by year, there will soon be such an accumulation that glaciers will begin to form. It is clear, therefore, that the conditions producing a Glacial period are likely to prove very complicated, and we need not be surprised if the conclusions to which we come are incapable of demonstration.

Theories respecting the cause of the Glacial period may be roughly classified as astronomical and geological. Among the astronomical theories, one which has sometimes been adduced is that the solar system in its movement through space is subjected to different degrees of heat at different times. According to this theory, the temperate climate which characterised the polar regions

during the Tertiary period, and continued up to the beginning of the Glacial epoch, was produced by the influence of the warmer stretches of space through which the whole solar system was moving at that time; while the Glacial period resulted from the influence upon the earth of the colder spaces through which the system subsequently moved.

While it is impossible absolutely to disprove this hypothesis, it labors under the difficulty of having little positive evidence in its favor, and thus contravenes a fundamental law of scientific reasoning, that we must have a real cause upon which to rest our theories. In endeavouring to explain the unknown, we should have something known to start with. But in this case we are not sure that there are any such variations in the temperature of the space through which the solar system moves. This theory, therefore, cannot come in for serious consideration until all others have been absolutely disproved. As we shall also more fully see, in the subsequent discussion, the distribution of the ice during the Glacial period was not such as to indicate a gradual extension of it from the north pole, but rather the accumulation upon centres many degrees to the south.

Closely allied with the preceding theory is the supposition broached by some astronomers that the sun is a variable star, dependent to some extent for its heat upon the impact of meteorites, or to the varying rapidity with which the contraction of its volume is proceeding.

It is well known that when two solid bodies clash together, heat is produced proportionate to the momentum of the two bodies. In other words, the motion which is arrested is transformed into heat. Mr. Croll, in his last publication * upon the subject, ingeniously attempted to account for the gaseous condition of the nebulæ and the

* Stellar Evolution and its Relation to Geological Time.

heat of the sun and other fixed stars by supposing it to be simply transformed motion. According to this theory, the original form of force imparted to the universe was that exerted in setting in motion innumerable dark bodies, which from time to time have collided with each other. The effects of such collisions would be to transform a large amount of motion into heat and its accompanying forms of molecular force. The violence of the compact of two worlds would be so great as to break them up into the original atoms of which they are composed, and the heat set free would be sufficient to keep the masses in a gaseous condition and cause them to swell out into enormous proportions. From that time on, as the heat radiated into space, there would be the gradual contraction which we suppose is going on in all the central suns, accompanied, of course, with a gradual decline of the heat-energy in the system.

Now, it is well known that the earth and the solar system in their onward progress pass through trains of meteorites. The tails of some of the comets are indeed pretty clearly proved to be streams of ponderable matter, through which, from time to time, the minor members of the solar system plunge, and receive some accession to their bulk and weight. The shooting-stars, which occasionally attract our attention in the sky, mark the course of such meteorites as they pass through the earth's atmosphere, and are heated to a glow by the friction with it. It has been suggested, therefore, that the sun itself may at times have its amount of heat sensibly affected by such showers of meteorites or asteroids. Upon this theory the warm period of the Tertiary epoch, for instance, may have been due to the heat temporarily added to the sun by impact with minor astronomical bodies. When, afterwards, it gradually cooled down, receiving through a long period no more accessions of heat from that source, the way was prepared for the colder epoch of the Glacial

period, which, in turn, was dispelled by fresh showers of meteorites upon the sun, sufficient to produce the amelioration of climate which we experience at the present time.

As intimated, this theory is closely allied to the preceding, the principal difference being that it limits the effects of the supposed cause to the solar system, and looks to our sun as the varying source of heat-supply. It has the advantage over that, however, of possessing a more tangible *vera causa.* Meteorites, asteroids, and comets are known to be within this system, and have occasional collisions with other members of it. But the principal objection urged against the preceding theory applies here, also, with equal force. The accumulations of ice during the Glacial period were not determined by latitude. In North America the centre of accumulation was south of the Arctic Circle—a fact which points clearly enough to some other cause than that of a general lowering of the temperature exterior to the earth.

The same objections would bear against the theory ably set forth by Mr. Sereno E. Bishop, of Honolulu, which, in substance, is that there may be considerable variability in the sun's emission of heat, owing to fluctuations in the rate of the shrinkage of its diameter, brought about by the unequal struggle between the diminishing amount of heat in the interior and the increasing force of the gravitation of its particles, and by the changes in the enveloping atmosphere of the sun, which, like an enswathing blanket, arrests a large portion of the radiant heat from the nucleus, and is itself evidently subject to violent movements, some of which seem to carry it down to the sun's interior. Unknown electrical forces, he thinks, may also combine to add an element of variability. These supposed changes may be compared to those which take place upon the surface of the earth when, at irregular intervals, immense sheets of lava, like those upon the Pacific coast of North America, are exuded in a compara-

tively brief time, to be succeeded by a long period of rest. The heat thus brought to the surface of the earth would add perceptibly to that radiated from it into space in ordinary times. Something similar to this upon the sun, it is thought, might produce effects perceptible upon the earth, and account for alternate periods of heat and cold.

A fourth astronomical theory is that there has been a shifting of the earth's axis; that at the time of the Glacial period the north pole, instead of being where it now is, was somewhere in the region of central Greenland. This is now maintained with some show of mathematical support by President T. C. Chamberlin and Professor G. C. Comstock,* but it likewise labours under a twofold difficulty: First, the shifting of the poles observed (450 feet per year) is too slight to have produced the changes within any reasonable time, and it is not likely to have been continuous for a long period. But still more fatal to the theory is the fact that the warm climate preceding the Glacial period seems to have extended towards the present north pole upon every side; a temperate flora having been found in the fossil plants of the Tertiary beds in Greenland and northern British America, as well as upon Nova Zembla and Spitzbergen.

A fifth astronomical theory, and one which has of late years been received with great favour, is that so ably advocated by the late Dr. James Croll and by Professor James Geikie. Following the suggestions of the astronomer Adhémar, these writers have attempted to show that not only one Glacial epoch, but a succession of such epochs, has been produced in the world by the effect of the changes which are known to have taken place in the

* See papers by these gentlemen read at the meeting of the American Association for the Advancement of Science, in Washington, in August, 1891. Professor Comstock's paper appeared in the American Journal of Science for January, 1892.

eccentricity of the earth's orbit when combined with the precession of the equinoxes—another calculable astronomical cause.

It is well known that the earth's orbit is elliptical; that is, it is longer in one direction than in the other, so that the sun is one side of the centre. During the winter of the northern hemisphere the earth is now about three

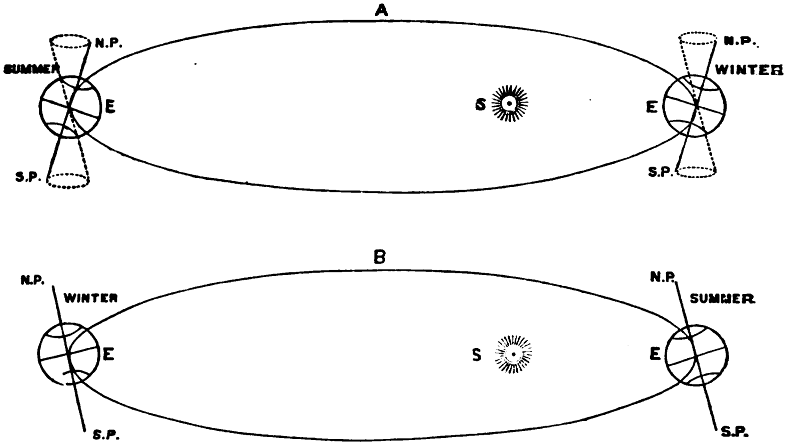

FIG. 99.—Diagram showing effect of precession: *A*, condition of things now; *B*, as it will be 10,500 years hence. The eccentricity is of course greatly exaggerated.

million miles nearer the sun than in the summer; but the summer makes up for this distance by being about seven days longer than the winter. Through the precession of the equinoxes this state of things will be reversed in ten thousand five hundred years; at which time we shall be nearer the sun during our northern summer, and farther away in winter, our winter then being also longer than our summer. Besides, through the unequal attraction of the planets the eccentricity of the earth's orbit periodically increases and diminishes, so that there have been periods when the earth was ten million five

hundred thousand miles farther from the sun in winter than in summer; at which times, also, the winter was nearly twenty-eight days longer than the summer. Such an extreme elongation of the earth's orbit occurred about two hundred and fifty thousand years ago.

It is easy to assume that such a change in astronomical conditions would produce great effects upon the earth's climate; and equally easy to connect with those effects the vast extension of ice during the Glacial period. Since, also, this period of extreme eccentricity terminated only eighty thousand years ago, the close of the Glacial period would, perhaps, upon Mr. Croll's theory, be comparatively a recent event; for if the secular summer of the earth's eccentricity lags relatively as far behind the secular movements as the annual summer does behind the vernal equinox, we should, as Professor Charles H. Hitchcock suggests, have to place the complete breaking up of the Ice period as late as forty thousand years ago.*

We have no space to indicate, as it deserves, the comparative merits and demerits of this ingenious theory. It would, however, be a great calamity to have geologists accept it without scrutiny. It is, indeed, a part of the business of geologists to doubt such theories until they are verified by a thorough examination of all accessible *terrestrial* evidence bearing upon the subject. There is no reason to question the reality of the variations in the relative positions of the earth and the sun assumed by Mr. Croll; though there may be serious doubt whether the effects of those changes upon climate would be all that is surmised, since equal amounts of heat would fall upon the earth during summer, whether made longer or shorter by the cause referred to. During the short summers the earth is so much nearer the sun that it receives each season absolutely as much heat as it does during the

* Geology of New Hampshire, vol. iii, p. 327.

longer summers, when it is so much farther away from the sun. Thus the theory rests at last upon the question what would become of the heat reaching the earth in these differing conditions. It is plausibly urged by Mr. Croll that when a hemisphere of the earth is passing through a period of long winters the radiation of heat will be so excessive that the temperature would fall much below what it would during the shorter winters; and so ice and snow would accumulate far beyond the usual amount. It is also supposed that the effect of the summer's sun in melting the ice during the short summer would be diminished through natural increase of the amount of foggy and cloudy weather.

Adhémar's theory is supposed by Sir Robert Ball, Royal Astronomer of Ireland, to be considerably re-enforced by a discovery which he has made concerning the distribution of heat upon the earth during the seasons culminating in the summer and winter solstices. Croll had assumed, on the authority of Herschel, that a hemisphere of the earth during the longer winter in aphelion would receive the same actual amount of heat which would fall upon it during the shorter summer in perihelion; whereas, according to Dr. Ball's discovery, "of the total amount of heat received from the sun on a hemisphere of the earth in the course of a year, sixty-three per cent is received during the summer and thirty-seven per cent during the winter."* When, therefore, the summers occur in perihelion the heat is more intense than Croll had supposed, and, at the same time, the winters occurring in aphelion are more deficient in heat than he had assumed. This discovery of Dr. Ball will not, however, materially affect the discussion of Croll's theory upon its inherent merits, since it is simply an intensification of the causes invoked by him. We will therefore let it stand or fall

* Cause of an Ice Age, p. 90.

in the light of the general considerations hereafter to be adduced.

The aid of theoretical consequent changes in the volume of the Gulf Stream, and in the area of the tradewinds, has also to be invoked by Mr. Croll. The theory likewise receives supposed confirmation from facts alleged concerning the present climate of the southern hemisphere which is passing through the astronomical conditions thought to be favourable to its glaciation. The antarctic continent is completely enveloped in ice, even down to the sixty-seventh degree of latitude. A few degrees nearer the pole Sir J. C. Ross describes the ice as rising from the water in a precipitous wall one hundred and eighty feet high. In front of such a wall, and nearly twenty degrees from the south pole, this navigator sailed four hundred and fifty miles! Voyagers, in general, are said to agree that the summers of the antarctic zone are much more foggy and cold than they are in corresponding latitudes in the northern hemisphere; and this, even though the sun is 3,000,000 miles nearer the earth during the southern summer than it is during the northern.

Another direction from which evidence is invoked in confirmation of Mr. Croll's theory is the geological indications of successive Glacial epochs in times past. If there be a recurring astronomical cause sufficient of itself to produce Glacial periods, such periods should recur as often as the cause exists; but glaciation upon the scale of that which immediately preceded the historic era could hardly have occurred in early geological time without leaving marks which geologists would have discovered. Were the "till" now covering the glaciated region to be converted into rock, its character would be unmistakable, and the deposit is so extensive that it could not escape notice.

In his inaugural address before the British Association in 1880, Professor Ramsey, Director-General of the Geological Survey of Great Britain, presented a formidable

list of glacial observations in connection with rocks of a remote age.* Beginning at the earliest date, he cites Professor Archibald Geikie, one of the most competent judges, as confident that the rounded knobs and knolls of Laurentian rocks exposed over a large region in northwestern Scotland, together with vast beds of coarse, angular, unstratified conglomerates, are unquestionable evidences of glacial action at that early period. Masses of similar conglomerates, resembling consolidated glacial boulder-beds, occur also in the Lower Silurian formation at Corswall, England. In Dunbar, Scotland, Professor Forbes also found, in formations of but little later age than the Coal period, "brecciated conglomerates, consisting of pebbles and large blocks of stone, generally angular, embedded in a marly paste, in which some of the pebbles are as well scratched as those found in medial moraines." In formations of corresponding antiquity the geologists of India have found similar boulder-beds, in which some of the blocks are polished and striated.

Still, this evidence is less abundant than we should expect, if there had been the repeated Glacial epochs supposed by Mr. Croll's astronomical theory; and it is by no means impossible that the conglomerates of scratched stones described by Professor Ramsey in Great Britain, and by Messrs. Blandford and Medlicott in India, may have resulted from local glaciers coming down from mountain-chains which have been since removed by erosion or subsidence. We are not aware that any incontestable evidence has been presented in America of any glaciation previous to that of *the* Glacial period.

Upon close consideration, also, it appears that Mr. Croll's theory has not properly taken into account the anomalous distribution of heat which we actually find to take place on the surface of the earth. He has done good

* Nature (August 26, 1880), vol. xxii, pp. 388, 389.

service in showing what an enormous transfer of heat there is from the southern to the northern Atlantic by means of the Gulf Stream, estimating that the heat conveyed by the Gulf Stream into the Atlantic Ocean is equal to one fifth of all possessed by the waters of the North Atlantic; or to the heat received from the sun upon a million and a half square miles at the equator, or two million square miles in the temperate zone. "The stoppage of the Gulf Stream would deprive the Atlantic of 77,479,-650,000,000,000,000 foot-pounds of energy in the form of heat per day."

Among the objections which bear against this ingenious theory is one which will appear with great force when we come to discuss the date of the Glacial period, when we shall show that even Professor Hitchcock's supposition that the lingering effects of the last great eccentricity of the earth's orbit, continued down to forty thousand years ago, is not sufficient to account for the recentness of the close of the period as shown by abundant geological evidence. It is certainly not more than ten or fifteen thousand years ago that the ice finally melted off from the Laurentian highlands; while on the Pacific coast the period of glaciation was still more recent.

From inspection of the accompanying map the main point of Mr. Croll's reasoning may be understood. It will be seen that the direction of the currents in the central Atlantic is largely determined by the contour of the northeastern coast of South America. From some cause the southeast trade-winds are stronger than the northeast, and their force is felt in pushing the superficial currents of warm water farther north than Cape St. Roque, the eastern extremity of Brazil. As the direction of the South American coast trends rapidly westward from this point to the Isthmus of Panama, the resultant of the forces is a strong current northwestward into the *cul-de-sac* of the Gulf of Mexico, from which there is only the one

outlet between Cuba and the peninsula of Florida. Through this the warm water is forced into the region where westerly winds prevail, and spreads its genial influence far to the northward, modifying the climate of the British Isles, and even of far-off Norway.

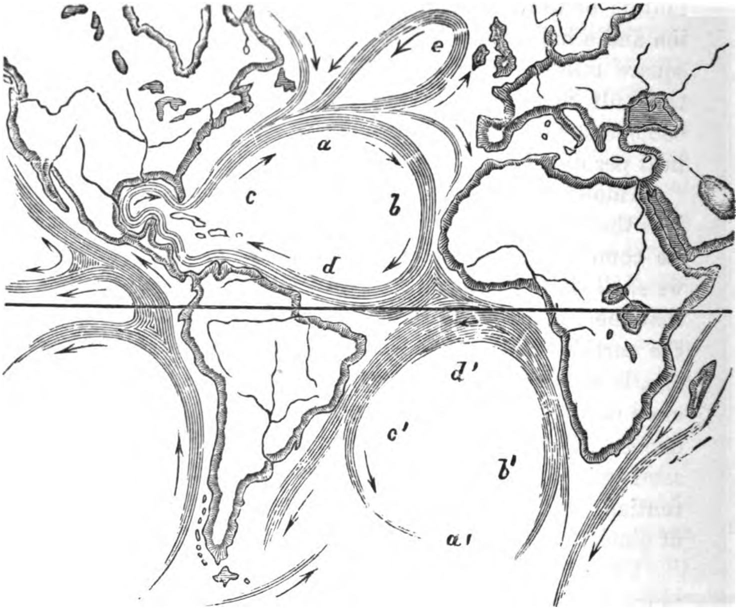

FIG. 100.—Map showing course of currents in the Atlantic Ocean: *b* and *b'* are currents set in motion by opposite trade-winds; meeting, they produce the equatorial current, which divides into *c* and *c'*, continuing on as *a* and *a'* and *e*.

But why are the southeast trade-winds of the Atlantic stronger than the northeast? The ultimate reason, of course, is to be found in the fact that the northern hemisphere is warmer than the southern. The atmosphere over the northern-central portion of the Atlantic region is more thoroughly rarefied by the sun's heat than is that over the region south of the equator. The strong southeast trades are simply the rush of atmosphere from the

South Atlantic to fill the vacuum caused by the heat of the sun north of the equator.

But, again, why is this? Because, says Mr. Croll, we are now in that stage of astronomical development favourable to the increased warmth of the northern hemisphere. In the northern hemisphere the summers are longer than the winters. Perihelion occurs in winter and aphelion in summer. This is the reason why the North Atlantic is warmer than the South Atlantic, and why the trade-winds of the south are drawn to the north of the equator. Ten thousand five hundred years ago, however, the conditions were reversed, and the greater rarefaction of the atmosphere would have taken place south of the equator, thus drawing the trade-winds in that direction.

By again inspecting the map, one will see how far-reaching the effect on the climate of northern countries this change in the prevalences of the trades would have been. Then, instead of having the northwest current leading along the northeast coast of South America into the Gulf of Mexico augmented by the warm currents circulating south of the equator, the warm currents of the north would have been pushed down so far that they would augment the current running to the southwest beyond Cape St. Roque, along the southeast shore of South America; thus the northern portion of the Atlantic, instead of robbing the southern portion of heat, would itself be robbed of its warm currents to contribute to the superfluous heat of the South Atlantic.

This theory is certainly very ingenious. There is a weak point in it, however. Mr. Croll assumes that when the winters of the northern hemisphere occur in aphelion, they must necessarily be colder than now. But, evidently, this assertion implies a fuller knowledge than we possess of the laws by which the heat received from the sun is distributed over the earth.

For it appears from observation that the equator is by

no means so hot now as, theoretically, it ought to be, and that the arctic regions are not so cold as, according to theory, they should be, and this in places which could not be affected by oceanic currents. For example, at Iquitos, on the Amazon, only three hundred feet above tide, three degrees and a half south of the equator, and more than a thousand miles from the Atlantic (so that ocean-currents cannot abstract the heat from its vicinity), the mean yearly temperature is but 78° Fahr.; while at Verkhojansk, in northeast Siberia, which is 67° north of the equator, and is situated where it is out of the reach of ocean-currents, and where the conditions for the radiation of heat are most favourable, and where, indeed, the winter is the coldest on the globe (January averaging — 56° Fahr.), the mean yearly temperature is two degrees and a half above zero; so that the difference between the temperature upon the equator and that at the coldest point on the sixty-seventh parallel is only about 75° Fahr.; whereas, if temperature were in proportion to heat received from the sun, the difference ought to be 172°. Again, the difference between the actual January temperature on the fiftieth parallel and that upon the sixtieth is but 20° Fahr., whereas, the quantity of solar heat received on the fiftieth parallel during the month of January is three times that received upon the sixtieth, and the difference in temperature ought to be about 170° Fahr. upon any known law in the case.

Woeikoff, a Russian meteorologist, and one of the ablest critics of Mr. Croll's theory, and to whom we are indebted for these facts, ascribes the greater present warmth of the northern Atlantic basin, not to the astronomical cause invoked by Mr. Croll, but to the relatively small extent of sea in the middle latitudes of the northern hemisphere. The extent and depth of the oceans of the southern hemisphere would of themselves give greater steadiness and force to its trade-winds, and lead to a gen-

eral lowering of the temperature; so that it is doubtful if the astronomical causes introduced by Mr. Croll, even with Dr. Ball's re-enforcement, would produce any appreciable effect while the distribution of land and water remains substantially what it is at the present time.

Still another variation in the astronomical theory has been set forth and defended by Major-General A. W. Drayson, F. R. A. S., instructor in the Royal Military School at Woolwich, England. He contends that what has been called the precession of the equinoxes, and supposed to be "a conical movement of the earth's axis in a circle around a point as a centre, from which it continually decreases its distance," * is really a second rotation of the earth about its centre. As a consequence of this second rotation, he endeavours to show that the inclination of the earth's axis varies as much as 12°; so that, whereas the Arctic and Antarctic Circles and the tropics extend to only about 23° from the poles and the equator, respectively, about thirteen thousand five hundred years ago they extended more than 35°; thus bringing the frigid zones in both cases 12° nearer the equator than now. This, he contends, would have produced the Glacial period at the time now more generally assigned to it by direct geological evidence.

The difficulty with this theory, even if the mathematical calculations upon which it is based are correct, would be substantially the same as those already urged against that of Mr. Croll. It is specially difficult to see how General Drayson would account for the prolonged temperate climate in high northern latitudes during the larger part of the Tertiary epoch.

It will be best to turn again to the map to observe the possible effect upon the Gulf Stream of a geological event of which we have some definite evidence, and which

* Untrodden Ground in Astronomy and Geology, p. 26.

is adduced by Mr. Upham and others as one of the important probable causes of the Glacial period, namely, the subsidence of the Isthmus of Panama and the adjacent narrow neck of land connecting North with South America. It will be seen at a glance that a subsidence sufficient to allow the northwest current of warm water, pushed by the trade-winds along the northeast shore of South America, to pass into the Pacific Ocean, instead of into the Gulf of Mexico, would be a cause sufficient to produce the most far-reaching results; it would rob the North Atlantic of the immense amount of heat and moisture now distributed over it by the Gulf Stream, and would add an equal amount to the northern Pacific Ocean, and modify to an unknown extent the distribution of heat and moisture over the lands of the northern hemisphere.

The supposition that a subsidence of the Isthmus of Darien was among the contributing causes of the Glacial period has been often made, but without any positive proof of such subsidence. From evidence which has recently come to light, however, it is certain that there has actually been considerable subsidence there in late Tertiary if not in post-Tertiary times. This evidence is furnished by Dr. G. A. Maack and Mr. William M. Gabb in their report to the United States Government in 1874 upon the explorations for a ship-canal across the isthmus, and consists of numerous fossils belonging to existing species which are found at an elevation of 150 feet above tide. As the dividing ridge is more than 700 feet above tide, this does not positively prove the point, but so much demonstrated subsidence makes it easy to believe, in the absence of contradictory evidence, that there was more, and that the isthmus was sufficiently submerged to permit a considerable portion of the warm equatorial current which now passes northward from the Caribbean Sea and the Gulf of Mexico to pass into the Pacific Ocean.

An obvious objection to the theory of a late Tertiary

or post-Tertiary subsidence of the Isthmus of Panama presents itself in the fact that there is at present a complete diversity of species between the fish inhabiting the

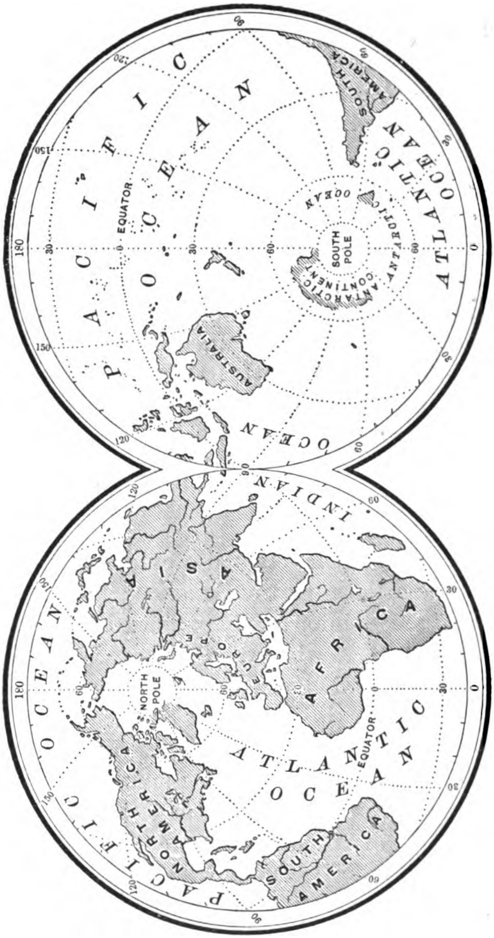

FIG. 101.—Map showing how the land clusters about the north pole.

waters upon the different sides of the isthmus. If there had been such a subsidence, it seems natural to suppose

that Atlantic species would have migrated to the Pacific side and obtained a permanent lodgment there, and that Pacific species would have found a congenial home on the Atlantic side. It must be confessed that this is a serious theoretical difficulty, but perhaps not insuperable. For it is by no means certain that colonists from the heated waters of the Caribbean Sea would become so permanently established upon the Pacific side that they could maintain themselves there upon the re-establishment of former conditions. On the contrary, it seems reasonable to suppose that upon the re-elevation of the isthmus the northern currents, which would then resume their course, would bring back with them conditions unfavourable to the Atlantic species, and favourable to the competing species which had only temporarily withdrawn from the field, and which might now be better fitted than ever to renew the struggle with their Atlantic competitors. It is by no means certain, therefore, that with the re-establishment of the former conditions there would not also be a re-establishment of the former equation of life upon the two sides of the isthmus.

Mr. Upham's theory involves also extensive elevations of land in the northern part of America; in this respect agreeing with the opinions early expressed by Professors J. D. Dana and J. S. Newberry. Of the positive indications of such northward elevations of land we have already spoken when treating in a previous chapter of the fiords and submerged channels which characterise northern Europe and both the eastern and the western coasts of North America. But in working out the problem the solution is only half reached when we have got the Gulf Stream into the Pacific Ocean, and the land in the northern part of the continents elevated to some distance above its present level. There is still the difficulty of getting the moisture-laden currents from the Pacific Ocean to carry their burdens over the crest of the Sierra Nevada

and Rocky Mountains and to deposit them in snow upon the Laurentian highlands. An ingenious supplement to the theory, therefore, has been brought forward by Professor Bailey, who suggests that the immense Tertiary and post-Tertiary lava-flows which cover so much of the area west of the Rocky Mountains were the cause of the accumulations of snow which formed the Laurentide Glacier. This statement, which at first seems so paradoxical as to be absurd, appears less so upon close examination.

The extent of the outflows of lava west of the Rocky Mountains is almost beyond comprehension. Literally, hundreds of thousands of square miles have been covered by them to a depth in many places of thousands of feet. These volcanic eruptions are mostly of late date, beginning in the middle of the Tertiary and culminating probably about the time of the maximum extent of the Laurentide Glacier. Indeed, so nearly contemporaneous was the growth of the Laurentide Glacier with these outflows that Professor Alexander Winchell had, with a good deal of plausibility, suggested that the outflows of the eruptions of lava were caused by the accumulation of ice over eastern British America. His theory was that the three million cubic miles of ice which is proved to have been abstracted from the ocean and piled up over that area was so serious a disturbance of the equilibrium of the earth's crust that it caused great fissures to be opened along the lines of weakness west of the Rocky Mountains, and pressed the liquid lava out, as the juice is pressed out of an orange in one place by pressing upon the rind in another.

Professor Bailey's theory is the exact reverse of Professor Winchell's. Going back to those orographic changes which produced the lava-flows and the elevation of the northern part of British America, he thinks the problem of getting the moisture transferred from the Pacific

Ocean to the Canadian highlands is solved by the lava-flows west of the Rocky Mountains. This immense exudation of molten matter was accompanied by an enormous liberation of heat, which must have produced significant changes in the meteorological conditions.

The moisture of the atmosphere is precipitated by means of the condensation connected with a lowering of its temperature. Ordinarily, therefore, when moist winds from an oceanic area pass directly over a lofty mountain-chain, the precipitation takes place immediately, and the water finds its way back by a short course to the sea. This is what now actually occurs on the Pacific coast. The Sierra Nevada condense nearly all the moisture; so that very little falls on the vast area extending from their summits eastward to the Rocky Mountains. All that region is now practically a desert land, where the evaporation exceeds the precipitation. In Professor Bailey's theory the heat radiated from the freshly exuded lava is supposed to have prevented the precipitation near the coast-line, and to have helped the winds in carrying it farther onward to the northeast, where it would be condensed upon the elevated highlands, upon which the snows of the great Laurentide Glacier were collected.

It is not necessary for us to attempt to measure the amount of truth in this susbidiary hypothesis of Professor Bailey, but it illustrates how complicated are the conditions which have to be considered before we rest securely upon any particular hypothesis. The unknown elements of the problem are so numerous, and so far-reaching in their possible scope, that a cautious attitude of agnosticism, with respect to the cause of the Glacial period, is most scientific and becoming. Still, we are ready to go so far as to say that Mr. Upham's theory comes nearest to giving a satisfactory account of all the phenomena, and it is to this that Professor Joseph Le Conte gives his cautious approval.

Summarily stated, this theory is, that the passage from the Tertiary to the Quaternary or Glacial period was characterised by remarkable oscillations of land-level, and by corresponding changes of climate, and of ice accumulation in northern regions; that the northern elevation was connected with subsidence in the equatorial regions; that these changes of land-level were both initiated and, in the main, continued by the interior geological forces of the globe; but that the very continental elevation which mainly brought on the Glacial period added at length, in the weight of the ice which accumulated over the elevated region, a new force to hasten and increase the subsidence, which would have taken place in due time in the natural progress of the orographic oscillations already begun. Professor Le Conte illustrates the subject by the following diagram, which, for simplicity's sake, treats the Glacial

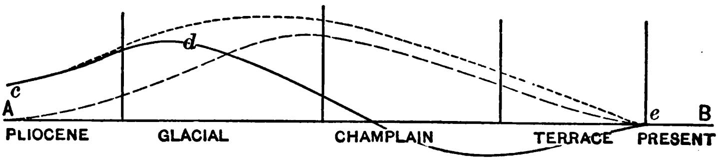

FIG. 102.

epoch as one; the horizontal line, *A B*, represents time from the later Pliocene until now; but it also represents the present condition of things both as to land-level and as to ice-accumulation. The full line, *c d e*, represents the oscillations of land (and presumably of temperature) above and below the present condition. The broken line represents the rise, culmination, and decline of ice-accumulation. The dotted line represents the crust-movement as it would have been if there had been no ice-accumulation.

It is seen from the diagram that the ice-accumulation culminated at a time when the land, under the pressure of the ice-load, had already commenced to subside; and

Succession of Epochs, Glacial and Fluvial Deposits, and

Epochs.	Eastern Provinces and New England.	Middle and Southern Atlantic States.
Recent or Terrace. (Mostly within the period of traditional and written history.)	Rise of the land to its present height, or somewhat higher, soon after the departure of the ice. Rivers eroding their glacial flood-plains, leaving remnants as terraces. Warmer climate than now, probably due to greater Gulf Stream, formerly permitted southern mollusks to extend to Gulf of St. Lawrence, now represented by isolated colonies.	Continued subsidence of coast at New York and southward, and rise of the mountainous belt, by displacement along the fall line of the rivers. Much erosion of the Columbia formation since culmination of second Glacial epoch; sedimentation in bays, sounds, and estuaries.
Glacial Period or Ice Age. Pleistocene Period. — Champlain. (Close of the second Glacial epoch.)	Land depressed under ice-weight; glacial recession; continued deposition of upper till and deep flood-plains of gravel, sand and clay (modified drift). Terminal moraines marking pauses or readvance during general retreat of ice. Marine submergence, 150 to 230 feet on coast of Maine, 0 to 520 feet in Gulf and valley of St. Lawrence.	Less subsidence in latitude of New York and southward than at north; lower Hudson Valley, and part of its present submarine continuation, above sea-level. Gravel and sand deposits from englacial drift in Delaware and Susquehanna Valleys, inclosing abundant human implements at Trenton, N. J.
Second Glacial.	Second great uplift of the land, 3,000 to 4,000 feet higher than now; snowfall again all the year; ice probably two miles thick on Laurentide highlands, and extending somewhat farther south here than in first glaciation. Lower till (ground moraine), and upper till (englacial drift). Terminal moraines, kames, osars, valley drift.	Renewal of great continental elevation (3,000 feet in latitude of New York and Philadelphia), of excessive snowfall and rains, and of wide-spread fluvial deposits, the Columbia formation, on the coastal plain, during early part of this epoch. Implements of man at Claymont, Del.
Inter-glacial. (Longest epoch of this era.)	Ice-sheet melted here; probably not more ice in arctic regions than now. Fluvial and lacustrine deposits of this time, with those of the first Glacial epoch, were eroded by the second glaciation.	Depression, but generally not to the present level. Deep channels cut in the bed-rocks by the Delaware, Susquehanna, Potomac, and other rivers. The Appomattox deposits much eroded. Relative length of this epoch made known by McGee from study of this region.
First Glacial.	Begun by high continental uplift, cool climate and snowfall throughout the year, producing ice-sheet. Much glacial erosion and transportation; till and stratified deposits. Ended by depression of land; return of warm climate, with rain; final melting of the ice. Isthmus of Panama probably submerged (Gulf Stream smaller), and again in second Glacial epoch.	Continental elevation; erosion of Delaware and Chesapeake Bays, and of Albemarle and Pamlico Sounds. Plentiful snowfall on the southern Appalachian Mountains; snows melted in summer, and heavy rains, producing broad river-floods, with deposition of the Appomattox formation.

Changes in Altitude and Climate, during the Quaternary Era.

Mississippi Basin and Northward.	Cordilleran Region.	Europe and Asia.
Terracing of river valleys. Northward rise of area of Lake Agassiz nearly complete before the ice was melted on the country crossed by Nelson River; but rise about Hudson Bay is still going on; 7,000 to 8,000 years since ice-melting uncovered Niagara and falls of St. Anthony.	Including a stage of considerable uplift, with return of humid conditions, Alpine glaciation (third Glacial epoch), and the second great rise of Lakes Bonneville and Lahontan. Very recent subsidence and change to present aridity.	Erosion and terracing of stratified drift in river valleys. Land passage of European flora to Greenland; succeeded by subsidence there, admitting warm currents to Arctic Sea. Minor climatic changes, including a warmer stage than now. Upper and outer portions of Indo-Gangetic alluvial plain; extensive deposits of Hwang Ho, and destructive changes of its course.
Abundant deposition of englacial drift. Stone implements in river gravels of Ohio, Ind., and Minn. Laurentian lakes held at higher levels, and Lake Agassiz formed in Red River basin, by barrier of retreating ice, with outlets over lowest points of their present southern watershed. Marine submergence 300 to 500 feet on southwest side of Hudson Bay.	Depression probably almost to the present level. Restoration of arid climate; nearly or quite complete evaporation of Lakes Bonneville and Lahontan. Formation of the "adobe" continuing through the second Glacial, Champlain, and Recent epochs.	Final departure of the ice-sheets; glacial rivers forming eskers and kames. Loess deposited while the region of the Alps was depressed lower than now. Upper (englacial) till, and asar, of Sweden. Marine submergence 500 to 600 feet in Scotland, Scandinavia, and Spitzbergen.
Ice-sheet here less extensive than in the first Glacial epoch, and not generally bordered as then by lakes in valleys which now drain southward. Terminal moraines at extreme limit of the ice-advance, and at ten or more stages of halt or readvance in its retreat.	Probable uplift 3,000 feet, shown by submerged valleys near Cape Mendocino. Second ice-sheet on British Columbia and Vancouver Island; local glaciation of Rocky Mountains, Cascade range, and Sierra Nevada, south to latitude 37°. First great rise of Lakes Bonneville and Lahontan.	Second elevation and general glaciation of northwestern Europe; the ice-sheets of Great Britain probably more extensive than in first Glacial epoch. Oscillations of ice-front; British Lower and Upper bowlder-clays, the Chalky, Purple, and Hessle bowlder-clays. Terminal moraines in Germany.
Depression nearly to present level southward; more northward, but followed there by differential uplift of 800 or 1,000 feet. Great erosion of loess and other modified drift, and of "Orange Sand." Valleys of this epoch, partly filled with later till, are marked by chains of lakes in southern Minnesota.	Continental depression. Arid climate. Long-continued denudation of the mountains; resulting very thick subaërial deposits of the "adobe." Intermittent volcanic action in various parts of this region, throughout the Quaternary era to very recent times, and liable to break forth again.	Recession, or probably complete departure, of the ice-sheets. Land connection between Europe and Africa, permitting southern animals to extend far northward. Erosion of the Somme Valley below its oldest implement-bearing gravels.
Pliocene elevation of continent brought to culmination at beginning of Quaternary era; this whole basin probably then uplifted 3,000 feet; excessive snowfall and rain; deposition of the "Orange Sand." Ice-sheet south to Cincinnati and St. Louis, at length depressing the earth's crust beneath it; slackened river floods and shallow lakes, forming the loess.	Latest rise (3,000 feet) of the Colorado Cañon district. Sierra Nevada and other Great Basin mountain-ranges formed by immense uplifts, with faulting. California river-courses changed; human bones and implements in the old river gravels, lava-covered. Ice-sheet on British Columbia; local glaciers southward.	Uplift and glaciation of northwestern Europe; maximum elevation, 2,500 feet or more (depth of the Skager Rack); France and Britain united with the Färöe Islands, Iceland, and Greenland. Uplifts of the Himalayas and other mountain-ranges attendant on both Glacial epochs.

that the subsidence was greatest at a time when the pressure had already begun to diminish. But the fact that the land, after the removal of the ice-load, did not return again to its former height in the Pliocene, is proof positive that there were other and more fundamental causes of crust-movement at work besides weighting and lightening. The land did not again return to its former level because the cycle of elevation, whatever its cause, which commenced in the Pliocene and culminated in the early Quaternary, had exhausted itself. If it had not been for the ice-load interfering with and modifying the natural course of the crust-movement determined previously and primarily by other and probably internal causes, the latter would probably have taken the course represented by the dotted line. It would have risen higher and culminated later, and its curve would have been of simpler form.

We append a carefully prepared table by Mr. Warren Upham, showing the probable changes in altitude and climate during the Quaternary era. *

On the part of many the theory here provisionally adopted will be regarded with disfavour by reason of a disinclination to supposing any great recent changes of level in the continental areas. So firmly established do the continents appear to be, that it seems like invoking an inordinate display of power to have them exalted for the sake of producing a Glacial period. Due reflection, however, will make it evident that within certain limits the continents are exceedingly unstable, and that they have displayed this instability to as great an extent in recent

* On page 106 and sequel I have summarised the reasons which lead me to discard the Inter-Glacial epoch, and to look upon the whole Glacial period as constituting a grand unity with minor episodes. It does not yet seem to me that the duality of the period is proved. On the contrary, Mr. Kendall's chapter on the Glacial phenomena of Great Britain strongly confirms my view.

geological times as they have done in any previous geological periods. When one reflects, also, upon the size of the earth, a continental elevation of 3,000 or 4,000 feet upon a globe whose diameter is more than 40,000,000 feet is an insignificant trifle. On a globe one foot in diameter it would be represented by a protuberance of barely one thousandth of an inch. A corresponding wrinkle upon a large apple would require a magnifying-glass for its detection. Moreover, the activity of existing volcanoes, the immense outflows of lava which have taken place in the later geological periods, together with the uniform increase of heat as we penetrate to deeper strata in the crust of the earth—all point to a condition of the earth's interior that would make the elevations of land which we have invoked for the production of the Glacial period easily credible. Physicists do not, indeed, now hold to the entire fluidity of the earth's interior, but rather to a solid centre, where gravity overcomes the expansive power of heat, and maintains solidity even when the heat is intense. But between the cooling crust of the earth's exterior and a central solid core there is now believed to be a film where the influences of heat and of the pressure of gravity are approximately balanced, and the space is occupied by a half-melted or viscous magma, capable of yielding to a slow pressure, and of moving in response to it from one portion of the enclosed space to another where the pressure is for any cause relieved.

As a result of prolonged enquiries respecting the nature of the forces at work both in the interior and upon the exterior of the earth, and of a careful study of the successive changes marking the geological period, we are led to believe that the continental elevations necessary to produce the phenomena of the Glacial period are not only entirely possible but easily credible, and in analogy with the natural progress of geological history. In the first place, it is easy to see that two causes are in operation

to produce a contraction of the earth's volume and a shortening of its diameter. Heat is constantly being abstracted from the earth by conduction and radiation, but perhaps to a greater extent through ceaseless volcanic eruptions which at times are of enormous extent. It requires but a moment's thought to see that contraction of the volume of the earth's interior means that the hardened exterior crust must adjust itself by wrinkles and folds. For a long period this adjustment might show itself principally in gentle swells, lifting portions of the continents to a higher level, accompanied by corresponding subsidence in other places. This gradually accumulating strain would at length be relieved along some line of special weakness in the crust by that folding process which has pushed up the great mountain systems of the world.

Careful study of the principal mountain systems shows that all the highest of them are of late geological origin. Indeed, the latter part of the Tertiary period has been the great mountain-building epoch in the earth's history. The principal part of the elevation of the Andes and the Rocky Mountains has taken place since the middle of the Tertiary period. In Europe there is indubitable evidence that the Pyrenees have been elevated eleven thousand feet during the same period, and that the western Alps have been elevated thirteen thousand feet in the same time. The Carpathians, the western Caucasus, and the Himalayas likewise bear explicit evidence to the fact that a very considerable portion of their elevation, amounting to many thousand feet, has been effected since the middle of the Tertiary period, while a considerable portion of this elevation of the chiefest mountain systems of the world has occurred in what would be called post-Tertiary time—that is, has been coincident with a portion of the Glacial period.

The Glacial period, however, we suppose to have been brought about, not by the specific plications in the earth's

crust which have produced the mountain-chains, but by the gentler swells of larger continental areas whose strain was at last relieved by the folding and mashing together of the strata along the lines of weakness now occupied by the mountain systems. The formation of the mountains seems to have relieved the accumulating strain connected with the continental elevations, and to have brought about a subsequent subsidence.

Doubtless, also, correlated subsidences and elevations of the earth's crust have been aided by the transfer of the sediment from continental to oceanic areas, and, as already suggested, during the Glacial period by the transfer of water evaporated from the surface of the ocean to the ice-fields of the glaciated area. For example, present erosive agencies are lowering the level of the whole Mississippi basin from the Alleghanies to the Rocky Mountains at the rate of a foot in five thousand years. All this sediment removed is being transferred to the ocean-bed. Present agencies, therefore, if not counteracted, would remove the whole continent of America (whose average elevation above the sea is only 748 feet) in less than four million years; while the great rivers which descend in all directions from the central plateau of Asia are transferring sediment to the ocean from two to four times as fast as the Mississippi is, and the Po is transferring it from the Alps to the Adriatic fully seven times as fast as the Mississippi is from its basin to the Gulf of Mexico. This rapid transfer of sediment from the continents to the ocean is producing effects in disturbing the present equilibrium of the earth's crust, which are too complicated for us fully to calculate; but it is by no means improbable that when accumulating for a considerable length of time, the ultimate results may be very marked and perhaps sudden in their appearance.

The same may also be said of the accumulation of ice during the Glacial period. The glaciated areas of North

America and Europe combined comprise about six million square miles. At a moderate estimate, the ice was three-quarters of a mile deep. Here, therefore, there would be between four and five million cubic miles of water, which had first relieved the ocean-beds of the pressure of its weight, and then concentrated its force over the elevated areas of the northern hemisphere. This disturbance of the equilibrium, by the known transfer of force from one part of the earth's crust to another, certainly gives much plausibility to the theory of Jamieson, Winchell, Le Conte, and Upham, that the Glacial period partly contained in itself its own cure, and by the weight of its accumulated weight of ice helped to produce that depression over the glaciated area which at length rendered the accumulation of ice there impossible.

This general view of the known causes in operation during the Glacial period will go far towards answering an objection that has probably before this presented itself to the reader's mind. It seems clear that the Glacial period in the southern hemisphere has been nearly contemporaneous with that of the northern. The Glacial period proper of the southern hemisphere is long since passed. The existing glaciers of New Zealand, of the southern portion of the Andes Mountains, and of the Himalaya Mountains are but remnants of those of former days. In the light of the considerations just presented, it would not seem improbable that the same causes should produce these similar effects in the northern and the southern hemisphere contemporaneously. At any rate, it would not seem altogether unlikely that the pressure of ice during the climax of the Glacial period upon the northern hemisphere (which, as we have seen, there is reason to believe aided in the depression of the continent to below its present level in the latter part of the Glacial period) should have contributed towards the elevation of mountains in other parts of the world, and so to the

temporary enlargement of the glaciers about their summits.

Nor are we wholly without evidence that these readjustments of land-level which have been carried on so vigorously since the middle of the Tertiary period are still going on with considerable though doubtless with diminished rapidity. There has been a re-elevation of the land in North America since the Glacial period amounting to 230 feet upon the coast of Maine, 500 feet in the vicinity of Montreal, from 1,000 to 1,600 feet in the extreme northern part of the continent, and in Scandinavia to the extent of 600 feet. In portions of Scandinavia the land is now rising at the rate of three feet in a century. Other indications of even the present instability of the earth's surface occur in numbers too numerous to mention.*

But, while we are increasingly confident that the main causes of the Glacial period have been changes in the relative relation of land-levels connected with diversion of oceanic currents, it is by no means impossible, as Wallace † and others have suggested, that these were combined with the astronomical causes urged by Drs. Croll and Geikie. By some this combination is thought to be the more probable, because of the extreme recentness of the close of the Glacial period, as shown by the evidence which will be presented in the following chapter. The continuance of glaciers in the highlands of Canada, down to within a few thousand years of the present time, coincides in a remarkable manner with the last occurrence of the conditions favourable to glaciation upon Mr. Croll's theory, which took place about eleven thousand years ago.

* For a convincing presentation of the views here outlined, together with abundant references to literature, see Mr. Warren Upham's Appendix to the author's Ice Age in North America.

† See Island Life, chapters viii and ix.

See "Science," xxii. 45; xxvi, 148, 754,

CHAPTER X.

THE DATE OF THE GLACIAL PERIOD.

In approaching the subject of glacial chronology, we are compelled to recognise at the outset the approximate character of all our calculations. Still, we shall find that there are pretty well-defined limits of time beyond which it is not reasonable to place the date of the close of the Glacial period; and, where exact figures cannot be determined, it may yet be of great interest and importance to know something near the limits within which our speculations must range.

For many years past Mr. Croll's astronomical theory as to the cause of the Glacial period has been considered in certain circles as so nearly established that it has been adopted by them as a chronological table in which to insert a series of supposed successive Glacial epochs which are thought to have characterised not merely the Quaternary epoch but all preceding geological eras. What we have already said, however, respecting the weakness of Mr. Croll's theory is probably sufficient to discredit it as a chronological apparatus. We will therefore turn immediately to the more tangible evidences bearing upon the subject.

The data directly relating to the length of time which separates the present from the Glacial period are mainly connected with two classes of facts:

1. The amount of erosion which has been accomplished by the river systems since the Glacial period; and 2. The

amount of sedimentation which has taken place in lakes and kettle-holes. We will consider first the evidence from erosion.

The gorge below Niagara Falls affords an important chronometer for measuring the time which has elapsed

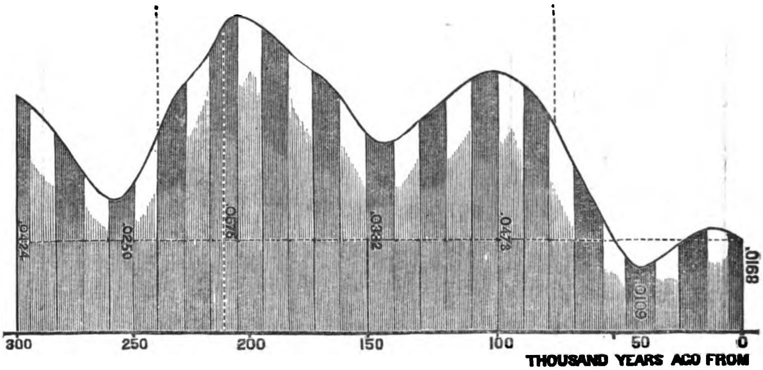

FIG. 103.—Diagram of eccentricity and precession: Absciss represents time and ordinates, degrees of eccentricity and also of cold. The dark and light shades show the warmer and colder winters, and therefore indicate each 10,500 years, the whole representing a period of 300,000 years.

since a certain stage in the recession of the great North American ice-sheet. As already shown, the present Niagara River is purely a post-glacial line of drainage;* the preglacial outlet to Lake Erie having been filled up by glacial deposits, so that, on the recession of the ice, the lowest level between Lake Erie and Lake Ontario was in the line of the trough of the present outlet. But, from what has already been said, it also appears that the Niagara River did not begin to flow until considerably after the ice-front had withdrawn from the escarpment at Queenston, where the river now emerges from its cañon to the low shelf which borders Lake Ontario. For a considerable period afterwards the ice continued to block up the easterly and northerly outlets through the valleys of the

* See above, p. 200 *et seq.*

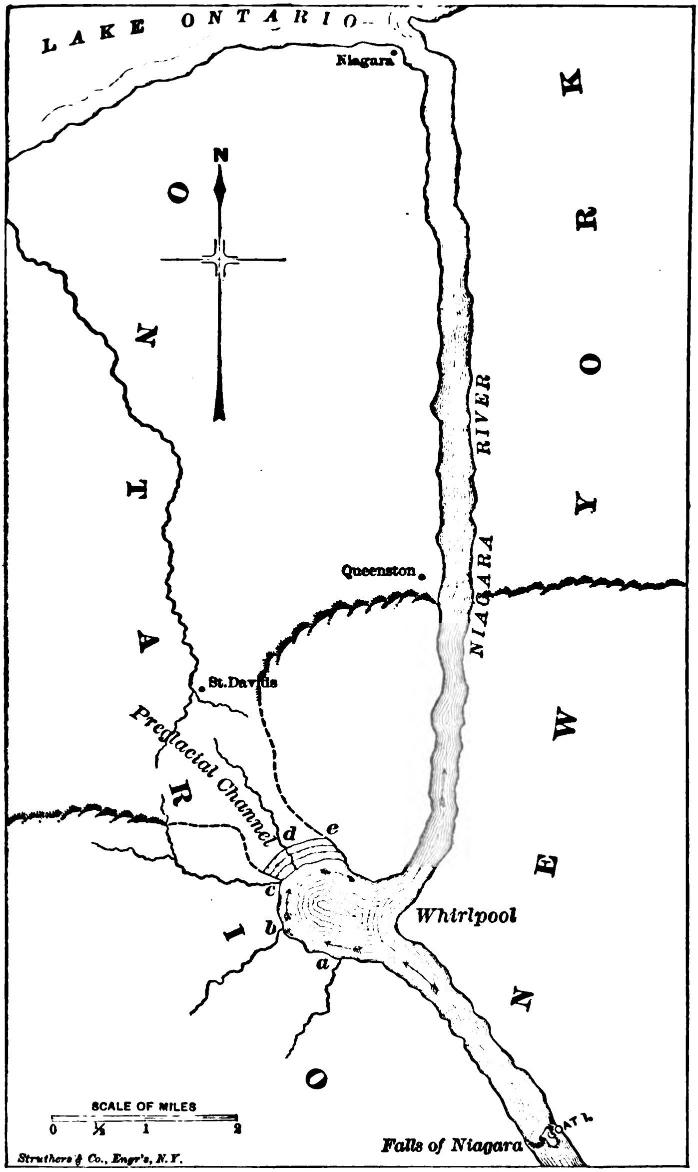

Fig. 104.—Map of the Niagara River below the falls, showing the buried channel from the whirlpool to St. Davids. Small streams, *a*, *b*, *c*, fall into the main gorge over a rocky escarpment. No rock appears in the channel at *d*, but the rocky escarpment reappears at *e*.

Mohawk and of the St. Lawrence, and held the water in front of the ice up to the level of the passes leading into the Mississippi Valley. Niagara River, of course, was not born until these ice-barriers on the east and northeast melted away sufficiently to allow the drainage to take its natural course.

Of these barriers, that across the Mohawk Valley doubtless gave way first. This would allow the confluent waters of this great glacial lake to fall down to the level of the old outlet from the basin of Lake Ontario into the Mohawk Valley, in the vicinity of Rome, N. Y. The moment, however, that the water had fallen to this level, the plunging torrents of Niagara would begin their work; and the gorge extending from Lewiston up to the present falls is the work done by this great river since that point of time in the Glacial period when the ice-barrier across the Mohawk Valley broke away.

The problem is therefore a simple one. Considering the length of this gorge as the dividend, the object is to find the rate of annual recession; this will be the divisor. The quotient will be the number of years which have elapsed since the ice first melted away from the Mohawk Valley. We are favoured in our calculation by the simplicity of the geologic arrangement.

The strata at Niagara dip slightly to the south, but not enough to make any serious disturbance in the problem. That at the surface, over which the water now plunges, consists of hard limestone, seventy or eighty feet in thickness, and this is continuous from the falls to the face of the escarpment at Queenston, where the river emerges from the gorge. Immediately underneath this hard superficial stratum there is a stratum of soft rock, of about the same thickness, which disintegrates readily. As a consequence, the plunging water continually undermines the hard stratum at the surface, and prepares the way for it to fall down, from time to time, in huge blocks,

which are, in turn, ground to powder by the constant commotion in which they are kept, and thus the channel is cleared of *débris*.

Below these two main strata there is considerable variation in the hardness of the rock, as shown in the accompanying diagram, where 3 and 5 are hard strata separated by a soft stratum. In view of this fact it seems probable that, for a considerable period in the early part of the recession, instead of there being simply one, there was a succession of cataracts, as the water unequally wore back through the harder strata, numbered 5, 3, and 1;

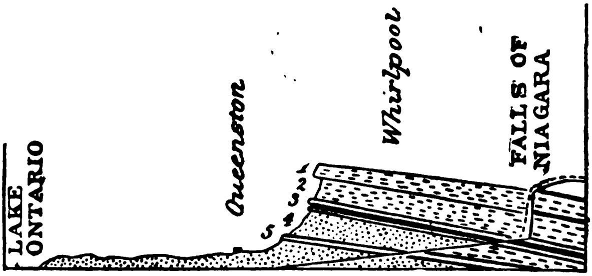

FIG. 105.—Section of strata along the Niagara gorge from the falls to the lake: 1, 3, strata of hard rock; 2, 4, of soft rock.

but, after having receded half the distance, these would cease to be disturbing influences, and the problem is thus really the simple one of the recession through the strata numbered 1 and 2, which are continuous. So uniform in consistency are these throughout the whole distance, that the rate of recession could never have been less than it is now. We come, therefore, to the question of the rapidity with which the falls are now receding.

In 1841 Sir Charles Lyell and Professor James Hall (the State Geologist of New York) visited the falls together, and estimated that the rate of recession could not be greater than one foot a year, which would make the time required about thirty-five thousand years. But Lyell thought this rate was probably three times too large; so

that he favoured extending the time to one hundred thousand years. Before this the eminent French geologist Desor had estimated that the recession could not have been more than a foot in a century, which would throw the beginning of the gorge back more than three million years. But these were mere guesses of eminent men, based on no well-ascertained facts; while Mr. Bakewell, an eminent English geologist, trusting to the data furnished him by the guides and the old residents of Niagara, had, even then, estimated that the rate of recession was as much as three feet a year, which would reduce the whole time required to about ten thousand years.

But the visit of Lyell and Hall in 1841 led to the beginning of more accurate calculations. Professor Hall soon after had a trigonometrical survey of the falls made, from which a map was published in the State geological report. From this and from the monuments erected, we have had since that time a basis of comparison in which we could place absolute confidence.

In recent years three surveys have been made: the first by the New York State Geologists, in 1875; and the third by Mr. R. S. Woodward, the mathematician of the United States Geological Survey, in 1886. The accompanying map shows the outlines of the falls at the time of these three measurements, from 1842 to 1886. According to Mr. Woodward, "the length of the front of the Horseshoe Fall is twenty-three hundred feet. Between 1842 and 1875 four and a quarter acres of rock were worn away by the recession of the falls. Between 1875 and 1886 a little over one acre and a third disappeared in a similar manner, making in all, from 1842 to 1886, about five and a half acres removed, and giving an annual rate of recession of about two feet and a half per year for the last forty-five years. But in the central parts of the curve, where the water is deepest, the Horseshoe Fall retreated

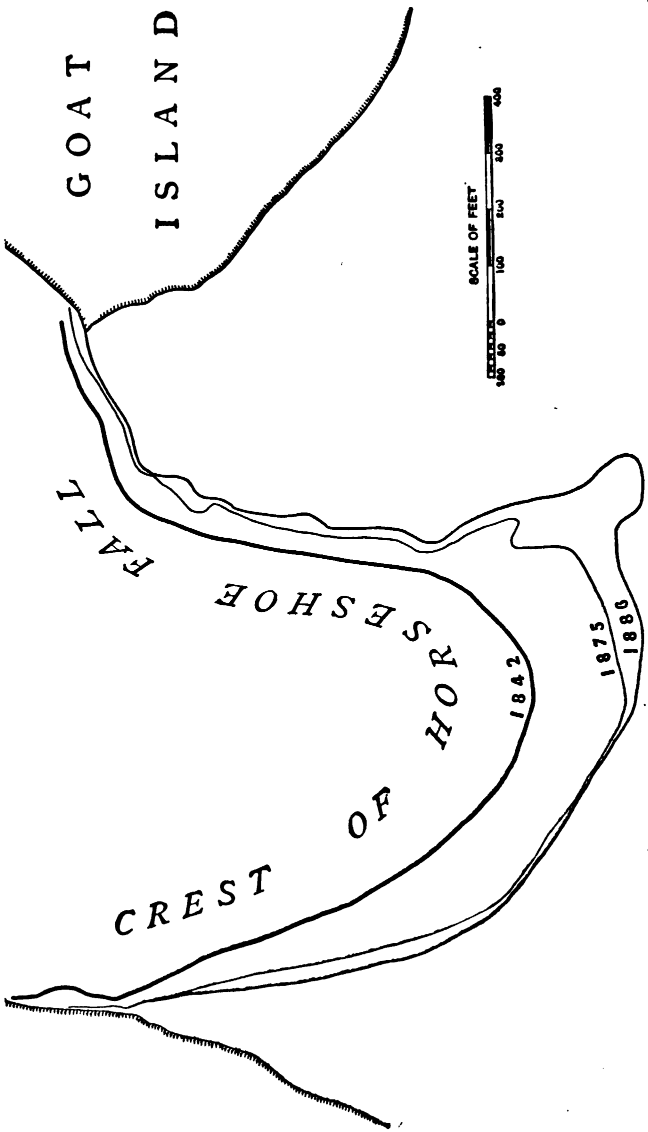

FIG. 106.—Map showing the recession of the Horseshoe Falls since 1842, as by survey mentioned in the text (Pohlman). (By the courtesy of the American Institute of Mining Engineers.)

between two hundred and two hundred and seventy-five feet in the eleven years between 1875 and 1886."

It will be perceived that the recession in the centre of the Horseshoe is very much more rapid than that nearer the margin; yet this rate at the centre is more nearly the standard of calculation than is that near the margin, for the gorge constantly tends to enlarge itself below the falls, and so gradually to bring itself into line with the full-formed channel. Taking all things into account, Mr. Woodward and the other members of the Geological Survey thought it not improbable that the average rate of actual recession in the Horseshoe Fall was as great as five feet per annum; and that, if we can rely upon the uniformity of the conditions in the past, seven thousand years is as long a period as can be assigned to its commencement.

The only condition in the problem about which there can be much chance of question relates to the constancy of the volume of water flowing in the Niagara channel. Mr. Gilbert has suggested that, as a consequence of the subsidence connected with the closing portions of the Glacial period, the water of the Great Lakes may have been largely diverted from its present outlet in Niagara River and turned northeastward, through Georgian Bay, French River, and Lake Nipissing, into a tributary of the Ottawa River, and so carried into the St. Lawrence below Lake Ontario. But of this theory no direct supporting evidence has been obtained. The gravel deposits which, upon that theory, should mark the *col* between Lake Nipissing and the Ottawa River have not been discovered. It seems probable that the region in the vicinity of Lake Nipissing, however much it may have been depressed during the maximum of glaciation, was re-elevated to about its present position before the St. Lawrence was reopened as an outlet to the waters of the Great Lakes. At any rate, there is much additional evidence to show that the pass to the Ottawa cannot have been long occupied.

A second noteworthy glacial chronometer is found in the gorge of the Mississippi River, extending from the Falls of St. Anthony, at Minneapolis, to its junction with the preglacial trough of the old Mississippi, at Fort Snelling, a distance likewise of about seven miles.

Above Fort Snelling the preglacial gorge is occupied by the Minnesota River, and, as we have before stated, extends to the very sources of this river, and is continuous with the southern portion of the valley of the trough of the Red River of the North. Before the Glacial period the drainage of the present basin of the upper Mississippi joined this main preglacial valley, not at Fort Snelling, but some little distance above, as shown upon our map.* This part of the preglacial gorge became partially filled up with glacial deposits, but it can be still traced by the lakelets occupying portions of the old depression, and by the records of wells which have been sunk along the line. When the ice-front had receded beyond the site of Minneapolis, the only line of drainage left open for the water was along the course of the present gorge from Minneapolis to Fort Snelling.

Here, as at Niagara, the problem is comparatively simple. The upper strata of rock consist of hard limestone, which is underlaid by a soft sandstone, which, like the underlying shale at Niagara, is eroded faster than the upper strata, and so a perpendicular fall is maintained. The strata are so uniform in texture and thickness that, with the present amount of water in the river, the rate of recession of the falls must have been, from the beginning, very constant. If, therefore, the rate can be determined, the problem can be solved with a good degree of confidence.

Fortunately, the first discoverer of the cataract—the Catholic missionary Hennepin—was an accurate observer,

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* See above, p. 209.

and was given to recording his observations for the instruction of the outside world and of future generations. From his description, printed in Amsterdam in 1704, Professor N. H. Winchell is able to determine the precise locality of the cataract when discovered in 1680.

Again, in 1766 the Catholic missionary Carver visited the falls, and not only wrote a description, but made a sketch (found in an account of his travels, published in London in 1788) which confirms the inferences drawn from Hennepin's narrative. The actual period of recession, however (which Professor Winchell duly takes into account), extends only to the year 1856, at which time such artificial changes were introduced as to modify the rate of recession and disturb further calculations. But between 1680 and 1766 the falls had evidently receded about 412 feet. Between 1766 and 1856 the recession had been 600 feet. The average rate is estimated by Professor Winchell to be about five feet per year, and the total length of time required for the formation of the gorge above Fort Snelling is a little less than eight thousand years, or about the same as that calculated by Messrs. Woodward and Gilbert for the Niagara gorge.

To these calculations of Professor Winchell it does not seem possible to urge any valid objection. It does not seem credible that the amount of water in the Mississippi should ever have been less than now, while during the continuance of the ice in the upper portion of the Mississippi basin the flow of water was certainly far greater than now.

If any one is inclined to challenge Professor Winchell's interpretation of the facts, even a hasty visit to the locality will suffice to produce conviction. The comparative youth of the gorge from Fort Snelling up to Minneapolis is evident: 1. From its relative narrowness, when compared with the main valley below. This is represented by the shading upon the map. The gorge from

Fort Snelling up is not old enough to have permitted much enlargement by the gradual undermining of the superficial strata on either side, which slowly but constantly goes on. 2. From the abruptness with which it merges into the preglacial valley of the Minnesota-Mississippi. The opening at Fort Snelling is not V-shaped, as in gorges where there has been indefinite time for the operation of erosive agencies. 3. Furthermore, the precipices lining the post-glacial gorge above Fort Snelling are far more abrupt than those in the preglacial valley below, and they give far less evidence of weathering. 4. Still, again, the tributary streams, like the Minnehaha River, which empty into the Mississippi between Fort Snelling and Minneapolis, flow upon the surface, and have eroded gorges of very limited extent; whereas, below Fort Snelling, the small streams have usually either found underground access to the river or occupy gorges of indefinite extent.

The above estimates, setting such narrow limits to post-glacial time in America, will seem surprising only to those who have not carefully considered the glacial phenomena of various kinds to be observed all over the glaciated area. As already said, the glaciated portion of North America is a region of waterfalls, caused by the filling up of old channels with glacial *débris*, and the consequent diversion of the water-courses. By this means the streams in countless places have been forced to fall over precipices, and to begin anew their work of erosion. Waterfalls abound in the glaciated region because post-glacial time is so short. Give these streams time enough, and they will wear their way back to their sources, as the preglacial streams had done over the same area, and as similar streams have done outside the glaciated region. Upon close observation, it will be found that the waterfalls in America are nearly all post-glacial, and that their work of erosion has been confined to a very limited time. A fair example is to be seen at Elyria, Ohio, in the falls of Black

River, one of the small streams which empty into Lake Erie from the south. Its post-glacial gorge, worn in sandstone which overlies soft shale, is only about two thousand feet in length, and it has as yet made no approach toward a V-shaped outlet.

The same impression of recent age is made by examining the outlets of almost any of the lakes which dot the glaciated area. The very reason of the continued existence of these lakes is that they have not had time enough to lower their outlets sufficiently to drain the water off, as has been done in all the unglaciated region. In many cases it is easy to see that the time during which this process of lowering the outlets has been going on cannot have been many thousand years.

The same impression is made upon studying the evidences of post-glacial valley erosion. Ordinary streams constantly enlarge their troughs by impinging against the banks now upon one side and now upon the other, and transporting the material towards the sea. It is estimated by Wallace that nine-tenths of the sedimentary material borne along by rivers is gathered from the immediate vicinity of its current, and goes to enlarge the trough of the stream. Upon measuring the cubical contents of many eroded troughs of streams in the glaciated region, and applying the tables giving the average amount of annual transportation of sediment by streams, we arrive at nearly the same results as by the study of the recession of post-glacial waterfalls.

Professor L. E. Hicks, of Granville, Ohio, has published the results of careful calculations made by him, concerning the valley of Raccoon Creek in Licking County, Ohio.* These show that fifteen thousand years would be more than abundant time for the erosion of the immediate valley adjoining that small stream. I have made and pub-

* See Baptist Quarterly for July, 1884.

lished similar calculations concerning Plum Creek, at Oberlin, in Lorain County, Ohio.* Like Raccoon Creek, this has its entire bed in glacial deposits, and has had nothing else to do since its birth but to enlarge its borders. The drainage basin of the creek covers an area of about twenty-five square miles. Its main trough averages about twenty feet in depth by five hundred in width, along a distance of about ten miles. From the rate at which the stream is transporting sediment, it is incredible that it could have been at work at this process more than ten thousand years without producing greater results.

Calculations based upon the amount of sediment deposited since the retreat of the ice-sheet point to a like moderate conclusion. When one looks upon the turbid water of a raging stream in time of flood, and considers that all the sediment borne along will soon settle down upon the bottom of the lake into which the stream empties, he can but feel surprised that the "wash" of the hills has not already filled up the depression of the lake. It certainly would have done so had the present condition of things existed for an indefinite period of time.

Naturally, while prosecuting the survey of the superficial geology of Minnesota, Mr. Upham was greatly impressed by the continued existence of the innumerable lakelets that give such a charm to the scenery of that State. Every day's investigations added to the evidence that the lapse of time since the Ice age must have been comparatively brief, since, otherwise, the rains and streams would have filled these basins with sediment, and cut outlets low enough to drain them dry, for in many instances he could see such changes slowly going forward.†

Some years ago I myself made a careful estimate of the

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* See Ice Age in North America, p. 469.

† Minnesota Geological Report for 1879, p. 73.

amount of deposition and vegetable accumulation which had taken place in a kettle-hole near Pomp's Pond, in Andover, Mass. The diameter of the depression at the rim

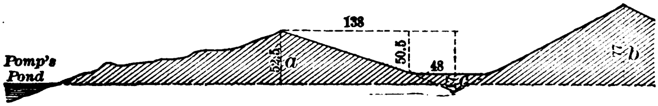

FIG. 107.—Section of kettle-hole near Pomp's Pond, Andover, Massachusetts (see text). (For general view of the situation, see Fig. 30, p. 78.)

was 276 feet. The inclination of the sides was such that the extreme depression of the apex of the inverted cone could not have been more than seventy feet; yet the accumulation of peat and sediment only amounted to a depth of seventeen feet. The total amount of material which had accumulated would be represented by a cone ninety-six feet in diameter at the base and seventeen feet at the apex, which would equal only a deposit of about five feet over the present surface of the bottom. It is easy to see that ten thousand years is a liberal allowance of time for the accumulation of five feet of sediment in the bottom of an enclosure like a kettle-hole, for upon examination it is clear that whatever insoluble material gets into a kettle-hole must remain there, since there is no possible way by which it can get out. Now five feet is sixty inches, and if this amount has been six thousand years in accumulating, that would represent a rate of an inch in one hundred years, while, if it has been twelve thousand years in accumulation, the rate will be only one two-hundredth of an inch per year, a film so small as to be almost inappreciable. If we may judge from appearance, the result would not be much different in the case of the tens of thousands of kettle-holes and lakelets which dot the surface of the glaciated region.

In the year 1869 Dr. E. Andrews, of Chicago, made an important series of calculations concerning the rate at which the waters of Lake Michigan are eating into the

shores and washing the sediment into deeper water or towards the southern end of the lake. With reference to the erosion of the shores, it appears from the work of the United States Coast Survey that a shoulder, covered with sixty feet of water, representing the depth at which wave-action is efficient in erosion, extends outward from the west shore a distance of about three miles, where the sounding line reveals the shore of the deeper original lake as it appeared upon the first withdrawal of the ice.

From a variety of observations the average rate at which the erosion of the bluffs is proceeding is found to be such that the post-glacial time cannot be more than ten thousand years, and probably not more than seven thousand.

An independent mode of calculating this period is afforded by the accumulations of sand at the south end of the lake, to which it is constantly drifting by the currents of water propelled against the shores by the wind; for the body of water in the lake is moving southward along the shores towards the closed end in that direction, there being a returning current along the middle of the lake. All the railroads approaching Chicago from the east pass through these sand deposits, and few of the observant travellers passing over the routes can have failed to notice the dunes into which the sand has been drifted by the wind. Now, all the material of these dunes and sand-beaches has been washed out of the bluffs to the northward by the process already mentioned, and has been slowly transferred by wave-action to its present position. It is estimated that south of Chicago and Grand Haven, this wave-transported sand amounts to 3,407,451,000 cubic yards. This occupies a belt curving around the south end about ten miles wide and one hundred miles long

The rate at which the sand is moving southward along the shore is found by observing the amount annually arrested by the piers at Chicago, Grand Haven, and

Michigan City. This equals 129,000 cubic yards for a year, which can scarcely be more than one quarter or one fifth of the total amount in motion. At this rate, the sand accumulations at the southern end of the lake would have been produced in a little less than seven thousand years.

"If," says Dr. Andrews, "we estimate the total annual sand-drift at only twice the amount actually stopped by the very imperfect piers built—which, in the opinion of the engineers, is setting it far too low—and compare it with the capacity of the clay-basin of Lake Michigan, we shall find that, had this process continued one hundred thousand years the whole south end of Lake Michigan, up to the line connecting Chicago and Michigan City, would have been full and converted into dry land twenty-five thousand years ago, and the coast-line would now be found many miles north of Chicago." *

It is proper to add a word in answer to an objection which may arise in the reader's mind, for it will doubtless occur to some to ask why this sand which is washed out by the waves from the bluffs is not carried inward towards the deeper portion of the trough of the lake, thus producing a waste which would partly counteract the forces of accumulation at the south end. The answer is found in the fact that the south end of Lake Michigan is closed, and that the currents set in motion by the wind are such that there is no off-shore motion sufficient to move sand, and, as a matter of fact, dredgings show that the sand is limited to the vicinity of the shore.

By comparing the eroded cliffs upon Michigan and the other Great Lakes with what occurs in similar situations about the glacial Lake Agassiz, we obtain an interesting means of estimating the comparative length of time occupied by the ice-front in receding from the Canadian border to Hudson Bay.

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* Southall's Recent Origin of Man, p. 502.

As we have seen, Lake Agassiz occupied a position quite similar in most respects to Lake Michigan. Its longest diameter was north and south, and the same forces which have eroded the cliffs of Lake Michigan and piled up sand-dunes at its southern end would have produced similar effects upon the shores of Lake Agassiz, had its continuance been anywhere near as long as that of the present Lake Michigan has been. But, according to Mr. Upham, who has most carefully surveyed the whole region, there are nowhere on the shores of the old Lake Agassiz any evidence of eroded cliffs at all to be compared with those found upon the present Great Lakes, while there is almost an entire lack of sand deposits about the south end such as characterise the shore of Lake Michigan. "The great tracts of dunes about the south end of Lake Michigan belong," as Upham well observes, "wholly to beach accumulations, being sand derived from erosion of the western and eastern shores of the lake. . . . But none of the beaches of our glacial lakes are large enough to make dunes like those on Lake Michigan, though the size and depth of Lake Agassiz, its great extent from north to south, and the character of its shores, seem equally favorable for their accumulation. It is thus again indicated that the time occupied by the recession of the ice-sheet was comparatively brief." *

From Mr. Upham's conclusions it would seem that if ten thousand years be allowed for the post-glacial existence of Lake Michigan, one tenth of that period would be more than sufficient to account for the cliffs, deltas, beaches, and other analogous phenomena about Lake Agassiz. In other words, the duration of Lake Agassiz could not have been more than a thousand years, which gives us a meas-

* Proceedings of the Boston Society of Natural History, vol. xxiv, p. 454; Upham's Glacial Lakes in Canada, in Bulletin of the Geological Society of America, vol. ii, p. 248.

ure of the rate at which the recession of the ice-front went on after it had withdrawn to the international boundary. The distance from there to the mouth of Nelson River is about 600 miles. The recession of the ice-front over that area proceeded, therefore, at the average rate of about half a mile per year.

There are many evidences that the main period of glaciation west of the Rocky Mountains was considerably later than that in the eastern part of the continent. A portion of the facts pointing to this conclusion have been well stated by Mr. George F. Becker, of the United States Geological Survey.

"No one," he says, "who has examined the glaciated regions of the Sierra can doubt that the great mass of the ice disappeared at a very recent period. The immense areas of polished surfaces fully exposed to the severe climate of say from 7,000 to 12,000 feet altitude, the insensible erosion of streams running over glaciated rocks, and the freshness of erratic boulders are sufficient evidence of this. There is also evidence that the glaciation began at no very distant geologic date. As Professor Whitney pointed out, glaciation is the last important geological phenomenon and succeeded the great lava flows. There is also much evidence that erosion has been trifling since the commencement of glaciation, excepting under peculiar circumstances. East of the range, for example, at Virginia City, andesites which there is every reason to suppose preglacial have scarcely suffered at all from erosion, so that depressions down which water runs at every shower are not yet marked with water-courses, while older rocks, even of Tertiary age and close by, are deeply carved. The rainfall at Virginia City is, to be sure, only about ten inches, so that rock would erode only say one third as fast as on the California coast; but even when full allowance is made for this difference, it is clear that these andesites must be much younger than the commencement of glaciation in

the northeastern portion of the continent as usually estimated. So, too, the andesites near Clear Lake, in California, though beyond a doubt preglacial, have suffered little erosion, and one of the masses, Mount Konocti (or Uncle Sam), has nearly as characteristic a volcanic form as Mount Vesuvius." *

This view of Mr. Becker is amply sustained by many other obvious facts, some of which may be easily observed by tourists who visit the Yosemite Park. The freedom of the abutting walls of this cañon from talus, as well as the freshness of the glacial scratches upon both the walls and the floor of the tributary cañons, all indicate a lapse of centuries only, rather than of thousands of years, since their occupation by glacial ice.

The freshness of the high-level terraces surounding the valleys of Great Salt Lake, in Utah, and of Pyramid and North Carson Lakes, in Nevada, and the small amount of erosion which has taken place since the formation of these terraces, point in the same direction—namely, to a very recent date for the glaciation of the Pacific coast.

We have already detailed the facts concerning the formation of these terraces and the evidence of their probable connection with the Glacial period. It is sufficient, therefore, here to add that, according to Mr. Russell and Mr. Gilbert (two of the most eminent members of the United States Geological Survey, who have each published monographs minutely embodying the results of their extensive observations in this region), the erosion of present streams in the beds which were deposited during the enlargement of the lakes is very slight, and the modification of the shores since the formation of the high terraces has been insignificant.

According to Mr. Gilbert: "The Bonneville shores

* Bulletin of the Geological Society of America, vol. ii, pp. 196, 197.

are almost unmodified. Intersecting streams, it is true, have scored them and interrupted their continuity for brief spaces; but the beating of the rain has hardly left a trace. The sea-cliffs still stand as they first stood, except that frost has wrought upon their faces so as to crumble away a portion and make a low talus at the base. The embankments and beaches and bars are almost as perfect as though the lake had left them yesterday, and many of them rival in the symmetry and perfection of their contours the most elaborate work of the engineer. There are places where boulders of quartzite or other enduring rock still retain the smooth, glistening surfaces which the waves scoured upon them by dashing against them the sands of the beach.

"When this preservation is compared with that of the lowest Tertiary rocks of the region—the Pliocene beds to which King has given the name Humboldt—the difference is most impressive. The Pliocene shore-lines have disappeared.

"The deposits are so indurated as to serve for building-stone. They have been upturned in many places by the uplifting of mountains. Elsewhere they have been divided by faults, and the fragments, dissevered from their continuation in the valley, have been carried high up on the mountain-flanks, where erosion has carved them in typical mountain forms. . . . The date of the Bonneville flood is the geologic yesterday, and, calling it yesterday, we may without exaggeration refer the Pliocene of Utah to the last decade, the Eocene of the Colorado basin to the last century, and relegate the laying of the Potsdam sandstone to prehistoric times." *

Mr. Russell adds to this class of evidence that of the small extent to which the glacial striæ have been effaced

* Second Annual Report of the United States Geological Survey, p. 188.

since the withdrawal of the ice from the borders of these old lakes: "The smooth surfaces are still scored with fine, hair-like lines, and the eye fails to detect more than a trace of disintegration that has taken place since the surfaces received their polish and striation. . . . It seems reasonable to conclude that in a severe climate like that of the high Sierra it" (the polish) "could not remain unimpaired for more than a few centuries at the most." *

Europe does not seem to furnish so favourable opportunities as America for estimating the date of the Glacial period; still it is not altogether wanting in data bearing upon the subject.

Some of the caves in which palæolithic implements were found associated with the bones of extinct animals in southern England contain floors of stalagmite which have been thought by some to furnish a measure of the time separating the deposits underneath from those above. This is specially true in the case of Kent's Cavern, near Torquay, which contains two floors of stalagmite, the upper one almost continuous and varying in thickness from sixteen inches to five feet, the lower one being in places twelve feet thick, underneath which human implements were found.

But it is difficult to determine the rate at which stalagmite accumulates. As is well known, this deposit is a form of carbonate of lime, and accumulates when water holding the substance in solution drops down upon the surface, where it is partially evaporated. It then leaves a thin film of the substance upon the floor. The rate of the accumulation will depend upon both the degree to which the water is saturated with the carbonate and upon the quantity of the water which percolates through the roof of the cavern. These factors are so variable, and so de-

* See also Mr. Upham in American Journal of Science, vol. xli, pp. 41, 51.

pendent upon unknown conditions in the past, that it is very difficult to estimate the result for any long period of time. Occasionally a quarter of an inch of stalagmite accretion has been known to take place in a cavern in a single year, while in Kent's Cavern, over a visitor's name inscribed in the year 1688, a film of stalagmite only a twentieth of an inch in thickness has accumulated. If, therefore, we could reckon upon a uniformity of conditions stretching indefinitely back into the past, we could determine the age of these oldest remains of man in Kent's Hole by a simple sum in arithmetic, and should infer that the upper layer of stalagmite required 240,000 years, and the lower 576,000 years, for their growth, which would carry us back more than 700,000 years, and some have not hesitated to affix as early a date as this to these lowest implement-bearing gravels.

But other portions of the cave show an actual rate of accretion very much larger. Six inches of stalagmite is there found overlying some remains of Romano-Saxon times which cannot be more than 2,000 years old. Assuming this as the uniform rate, the total time required for the deposit of the stalagmitic floors would still be about 70,000 years. But, as we have seen, the present rates of deposition are probably considerably less than those which took place during the moister climate of the Glacial epoch. Still, even by supposing the rate to be increased fourfold, the age of this lower stratum would be reduced to only 12,000 years. So that, as Mr. James Geikie well maintains, "Even on the most extravagant assumption as to the former rate of stalagmitic accretion, we shall yet be compelled to admit a period of many thousands of years for the formation of the stalagmitic pavements in Kent's Cavern." * We should add, however, that there is much well-founded doubt whether the implements found in the

* Prehistoric Europe, p. 88.

lowest stratum were really in place, since, according to Dr. Evans, "Owing to previous excavations and to the presence of burrowing animals, the remains from above and below the stalagmite have become intermingled." *

An attempt was made by M. Morlot in Switzerland to obtain the chronology of the Glacial period by studying the deltas of the streams descending the glaciated valleys. He paid special attention to that of the Tinière, a stream which flows into Lake Geneva near Villeneuve. The modern delta of this stream consists of gravel and sand deposited in the shape of a flattened cone, and investigations upon it were facilitated by a long railroad cutting through it. "Three layers of vegetable soil, each of which must at one time have formed the surface of the cone, have been cut through at different depths." † In the upper stratum Roman tiles and a coin were found; in the second stratum, unvarnished pottery and implements of bronze; while in the lower stratum, at a depth of nineteen feet from the surface, a human skull was found, to which Morlot assigned an age of from 5,000 to 7,000 years.

But Dr. Andrews, after carefully revising the data, felt confident that the time required for the whole deposit of this lower delta was not more than 5,000 years, and that the oldest human remains in it, which were about half way from between the base and the surface of the cone, were probably not more than 3,000 years old.

Still, the significance of this estimate principally arises from the relation of the modern delta to older deltas connected with the Glacial period. Above this modern delta, formed by the river in its present proportions, there is another, more ancient, about ten times as large, whose accumulation doubtless took place upon the final retreat of the ice from Lake Geneva. No remains of man have been

* Stone and Flint Implements, p. 446.

† Lyell's Antiquity of Man, p. 28.

found in this, but it doubtless corresponds in age with the high-level gravels in the valley of the Somme, in which the remains of man and the mammoth, together with other extinct animals, have been found.

We do not see, however, that any very definite calculation can be made concerning the time required for its deposition. Lyell was inclined to consider it ten times as old as the modern delta, simply upon the ground of its being ten times as large. On Morlot's estimate of the age of the modern delta, therefore, the retreat of the ice whose melting torrents deposited the upper delta would be fixed at 100,000 years ago, and upon Dr. Andrews's calculation, at about 20,000.

But it is evident that the problem is not one of simple multiplication. The floods of water which accompanied the melting back of the ice from the upper portions of this valley must have been immensely larger than those of the present streams, and their transporting power immensely greater still. Hence we do not see that any conclusions can be drawn from the deltas of the Tinière to give countenance to extreme views concerning the date of the close of the Glacial period.*

In the valley of the Somme the chronological data relating to the Glacial period, and indicating a great antiquity for man, have been thought to be more distinct than anywhere else in Europe. As already stated, it is the prevalent opinion that since man first entered the valley, in connection with the mammoth and the other extinct animals characteristic of the Glacial period, the trough of the Somme, about a mile in width and a hundred feet in depth, has been eroded by the drainage of its present valley. An extensive accumulation of peat also has taken place along the bottom of the trough of the river since it was originally eroded to its present level.

* Lyell's Antiquity of Man, p. 321.

This substance occurs all along the bottom of the valley from far above Amiens to the sea, and is in some places more than thirty feet in depth. The animal and vegetable remains in it all belong to species now inhabiting Europe.

The depth of the peat indicates that when it was formed the land stood at a slightly higher elevation than now, for the base of the stratum is now below the sea-level, while the peat is of fresh-water origin, and, according to Dr. Andrews,* is formed from the vegetable accumulations connected with forest growths. When, therefore, the country was covered with forests, as it was in prehistoric times, the accumulation must have proceeded with considerable rapidity. This inference is confirmed by the occurrence in the peat of prostrate trunks of oak, four feet in diameter, so sound that they were manufactured into furniture. The stumps of trees, especially of the birch and alder, were also found in considerable number, standing erect where they grew, sometimes to a height of three feet. Now, as Dr. Andrews well remarks, it is evident that, in order to prevent these stumps and prostrate trunks from complete decay, the accumulation of peat must have been rapid. From certain Roman remains found six feet and more beneath the surface, he estimates that the accumulation since the Roman occupation has been as much as six inches a century, at which rate the whole would take place in somewhat over 5,000 years.

Still, if we accept this estimate, we have obtained but a starting-point from which to estimate the age of the high-level gravels in which palæolithic implements were found; for, if we accept the ordinary theory, we must add to this the time required for the river to lower its bed from eighty to a hundred feet, and to carry out to the sea the contents of its wide trough. But, as already shown,

* American Journal of Science, October, 1868.

the Glacial period was, even in the north of France, a time of great precipitation and of a considerable degree of cold, when ice formed to a much greater extent than now upon the surface of the Somme. The direct evidence of this consists in the boulders mingled with the high-level gravel which are of such size as to require floating ice for their transportation.

In addition to the natural increase in the eroding power of the Somme brought about by the increase in its volume, on account of the greater precipitation in the Glacial age, there would also be, as Prestwich has well shown, a great increase in rate through the action of ground ice, which plays a very important part in the river erosion of arctic countries, and in all probability did so during the Glacial period in the valley of the Somme.

"When the water is reduced to and below 32° Fahr., although the rapid motion may prevent freezing on the surface for a time, any pointed surfaces at the bottom of the river, such as stones and boulders, will determine (as is the case with a saturated saline solution) a sort of crystallisation, needles of ice being formed, which gradually extend from stone to stone and envelop the bodies with which they are in contact. By this means the whole surface of a gravelly river-bed may become coated with ice, which, on a change of temperature, or of atmospheric pressure, or on acquiring certain dimensions and buoyancy, rises to the surface, bringing with it the loose materials to which it adhered. Colonel Jackson remarks, in speaking of this bottom-ice, that 'it frequently happens that these pieces, in rising from the bottom, bring up with them sand and stones, which are thus transported by the current. . . . When the thaw sets in the ice, becoming rotten, lets fall the gravel and stones in places far distant from those whence they came.'

"Again, Baron Wrangell remarks that, 'in all the more rapid and rocky streams of this district [northern Siberia]

the formation of ice takes place in two different manners; a thin crust spreads itself along the banks and over the smaller bays where the current is least rapid; but the greater part is formed in the bed of the river, in the hollows among the stones, where the weeds give it the appearance of a greenish mud. As soon as a piece of ice of this kind attains a certain size, it is detached from the ground and raised to the surface by the greater specific gravity of the water; these masses, containing a quantity of gravel and weeds, unite and consolidate, and in a few hours the river becomes passable in sledges instead of in boats.' Similar observations have been made in America; but instances need not be multiplied, as it is a common phenomenon in all arctic countries, and is not uncommon on a small scale even in our latitudes.

"The two causes combined—torrential river-floods and rafts of ground-ice, together with the rapid wear of the river cliffs by frost—constituted elements of destruction and erosion of which our present rivers can give a very inadequate conception; and the excavations of the valleys must have proceeded with a rapidity with which the present rate of erosion cannot be compared; and estimates of time founded on this, like those before mentioned on surface denudation, are therefore not to be relied upon." *

Speaking a little later of taking the present rates of river erosion as a standard to estimate the chronology of the Glacial period, the same high authority remarks: "It no more affords a true and sufficient guide than it would be to take the tottering paces and weakened force of an old man as the measure of what that individual was, and what he could do, in his robust and active youth. It may be right to take the effects at present produced by a given power as the known quantity, *a*, but it is equally indispensable, in all calculations relative to the degree of those

* Prestwich's Geology, vol. ii, pp. 471, 472.

forces in past times, to take notice of the unknown quantity, x, although this, in the absence of actual experience, which cannot be had, can only be estimated by the results and by a knowledge of the contemporaneous physical conditions. It may be a complicated equation, but it is not to be avoided.*

"In this country and in the north of France broad valleys have been excavated to the depth of from about eighty to a hundred and fifty feet in glacial and postglacial times. Difficult as it is by our present experience to conceive this to have been effected in a comparatively short geological term, it is equally, and to my mind more, difficult to suppose that man could have existed eighty thousand years or more, and that existing forms of our fauna and flora should have survived during two hundred and forty thousand years without modification or change." †

The discussion of the age of the high-level river gravels of the Somme and other streams in northwestern Europe is not complete, however, without considering another possibility as to the mode of their deposition. The conclusion to which Mr. Alfred Tylor arrived, after a prolonged and careful study of the subject, was that the main valleys of the Somme and other streams in northern France and southern England were preglacial in their origin, and that the accumulations of gravel at high levels along their margin were due to enormous floods which characterised the closing portion of the great ice age, which he denominated the pluvial period.‡ The credibility of floods large enough to accomplish the results manifest in the valley of the Somme is supported by reference to a flood which occurred on the Mulleer River, in India, in 1856, when a

* Prestwich's Geology, pp. 520, 521.

† Ibid., p. 533.

‡ Proceedings of the Geological Society, London, November 8, 1867, pp. 103–126; Quarterly Journal of the Geological Society, February 1, 1869, pp. 57–100.

stream, which is usually insignificant, was so swollen by a rainfall of a single day that it rose high enough to sweep away an iron bridge the bottoms of whose girders were sixty-five feet above high-water mark. One iron girder weighing eighty tons was carried two miles down the river, and nearly buried in sand. The significance of these facts is enhanced by observing also that for fifteen miles above the bridge the fall of the river only averaged ten feet per mile. Floods to this extent are not uncommon in India. During the Glacial period spring freshets must have been greatly increased by the melting of a large amount of snow and ice which had accumulated during the winter, and also by the formation of ice-gorges near the mouths of many of the streams. It is probable, also, that the accumulation of ice across the northern part of the German Ocean may have permanently flooded the streams entering that body of water; for it is by no means improbable that there was a land connection between England and France across the Straits of Dover until after the climax of the Glacial period. In support of his theory, Mr. Tylor points to the fact "that the gravel in the valley of the Somme at Amiens is partly derived from *débris* brought down by the river Somme and by the two rivers the Celle and the Arve, and partly consists of material from the adjoining higher grounds washed in by land floods," and that the "Quaternary gravels of the Somme are not separated into two divisions by an escarpment of chalk parallel to the river," but "thin out gradually as they slope from the high land down to the Somme."

Mr. Tylor's reasoning seems especially cogent to one who stands on the ground where he can observe the size of the valley and the diminutive proportions of the present stream. Even if we do not grant all that is claimed by Mr. Tylor, it is difficult to resist the main force of his argument, and to avoid the conclusion that the valley of the Somme is largely the work of preglacial erosion, and

has been, at any rate, only in slight degree deepened and enlarged during post-Tertiary time.

SUMMARY.

In briefly summarising our conclusions concerning the question of man's antiquity as affected by his known relations to the Glacial period, it is important, first, to remark upon the changes of opinion which have taken place with respect to geological time within the past generation. Under the sway of Sir Charles Lyell's uniformitarian ideas, geologists felt themselves at liberty to regard geological time as practically unlimited, and did not hesitate to refer the origin of life upon the globe back to a period of 500,000,000 years. In the first edition of his Origin of Species Charles Darwin estimated that the time required for the erosion of the Wealden deposits in England was 306,662,400 years, which he spoke of as "a mere trifle" of that at command for establishing his theory of the origin of species through natural selection. In his second edition, however, he confesses that his original statement concerning the length of geological time was rash; while in later editions he quietly omitted it.

Meanwhile astronomers and physicists have been gradually setting limits to geological time until they have now reached conclusions strikingly in contrast with those held by the mass of English geologists forty years ago. Mr. George H. Darwin, Professor of Mathematics at Cambridge University, has from a series of intricate calculations shown that between fifty and one hundred million years ago the earth was revolving from six to eight times faster than now, and that the moon then almost touched the earth, and revolved about it once every three or four hours. From this proximity of the moon to the earth, it would result that if the oceans had been then in existence the tides would have been two hundred times as great as now, creating a wave six hundred feet in height, which

would sweep around the world every four hours. Such a condition of things would evidently be incompatible with geological life, and geology must limit itself to a period which is inside of 100,000,000 years. Sir William Thomson and Professor Tait, of Great Britain, and Professor Newcomb, of the United States Naval Observatory, approaching the question from another point of view, seem to demonstrate that the radiation of heat from the sun is diminishing at a rate such that ten or twelve million years ago it must have been so hot upon the earth's surface as to vaporise all the water, and thus render impossible the beginning of geological life until later than that period. Indeed, they seem to prove by rigorous mathematical calculations that the total amount of heat originally possessed by the nebula out of which the sun has been condensed would only be sufficient to keep up the present amount of radiation for 18,000,000 years.

The late Dr. Croll, feeling the force of these astronomical conclusions, thought it possible to add sufficiently to the sun's heat to extend its rule backwards approximately 100,000,000 years by the supposition of a collision with it of another moving body of near its own size. Professor Young and others have thought that possibly the heat of the sun might have been kept up by the aid of the impact of asteroids and meteorites for a period of 30,000,000 years. Mr. Wallace obtains similar figures by estimating the time required for the deposition of the stratified rocks open to examination upon the land surface of the globe. As a result of his estimates, it would appear that 28,000,000 years is all the time required for the formation of the geological strata. From all this it is evident that geologists are much more restricted in their speculations involving time than they thought themselves to be a half-century ago. Taking as our standard the medium results attained by Wallace, we shall find it profitable to see how this time can be por-

tioned out to the geological periods, that we may ascertain how much approximately can be left for the Glacial epoch.

On all hands it is agreed that the geological periods decrease in length as they approach the present time. According to Dana's estimates,* the "ratio for the Palæozoic, Mesozoic, and Cenozoic periods would be 12 : 3 : 1"—that is, Cenozoic time is but one sixteenth of the whole. This embraces the whole of the Tertiary period, during which placental mammals have been in existence, together with the post-Tertiary or Glacial period, extending down to the present time; that is, the time since the beginning of the Tertiary period and the existence of the higher animals is considerably less than two million years, even upon Mr. Wallace's basis of calculation. But if we should be compelled to accept the calculations of Sir William Thomson, Professor Tait, and Professor Newcomb, the Cenozoic period would be reduced to considerably less than one million years. It is difficult to tell how much of Cenozoic time is to be assigned to the Glacial period, since there is, in fact, no sharply drawn line between the two periods. The climax of the Glacial period represented a condition of things slowly attained by the changes of level which took place during the latter part of the Tertiary epoch.

In order to estimate the degree of credibility with which we may at the outset regard the theory of Mr. Prestwich and others, that all the phenomena of the Glacial period can be brought within the limits of thirty or forty thousand years, it is important to fix our minds upon the significance of the large numbers with which we are accustomed to multiply and divide geological quantities.†

* See revised edition of his Geology, p. 586.

† See Croll's Climate and Time, chap. xx.

Few people realise either the rapidity with which geological changes are now proceeding or the small amount of change which might produce a Glacial period, and fewer still have an adequate conception of how long a period a million years is, and how much present geological agencies would accomplish in that time. At the present rate at which erosive agencies are now acting upon the Alps, their dimensions would be reduced one half in a million years. At the present rate of the recession of the Falls of St. Anthony, the whole gorge from St. Louis to Minneapolis would have been produced in a million years. A river lowering its bed a foot in a thousand years would produce a cañon a thousand feet deep in a million years.

If we suppose the Glacial period to have been brought about by an elevation of land in northern America and northern Europe, proceeding at the rate of three feet a century, which is that now taking place in some portions of Scandinavia, this would amount to three thousand feet in one hundred thousand years, and that is probably all, and even more than all, which is needed. One hundred thousand years, therefore, or even less, might easily include both the slow coming on of the Glacial period and its rapid close. Prestwich estimates that the ice now floating away from Greenland as icebergs is sufficient if accumulating on a land surface to extend the borders of a continental glacier about four hundred and fifty feet a year, or one mile in twelve years, one hundred miles in twelve hundred years, and seven hundred miles (about the limit of glacial transportation in America) in less than ten thousand years.

After making all reasonable allowances, therefore, Prestwich's conclusion that twenty-five thousand years is ample time to allow to the reign of the ice of the Glacial period cannot be regarded as by any means incredible or, on *a priori* grounds, improbable.

APPENDIX.

THE TERTIARY MAN.

By Professor Henry W. Haynes.

"It must not be imagined that it is in any way proved that the Palæolithic man was the first human being that existed. We must be prepared to wait, however, for further and better authenticated discoveries before carrying his existence back in time further than the Pleistocene or post-Tertiary period." * This was the position assumed more than twelve years ago by the eminent English geologist and archæologist, Dr. John Evans, and it was still maintained in his address before the Anthropological Section of the British Association on September 18, 1890.* I believe that the study of all the evidence in favor of the existence of the Tertiary man that has been brought forward down to the present time will leave the question in precisely the same state of uncertainty.

"In order to establish the existence of man at such a remote period the proofs must be convincing. It must be shown, first, that the objects found are of human workmanship; secondly, that they are really found as stated; and, thirdly, the age of the beds in which they are found must be clearly ascertained and determined." † These tests I propose to apply to the evidence for the Tertiary man recently brought

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* *A Few Words on Tertiary Man*, Trans. of Hertfordshire Nat. Hist. Soc., vol. i, p. 150.

† Ibid., p. 148.

*See Smithsonian Rep. ..., 1890, p. 467.

forward in Europe, and then to consider the significance of certain discoveries on the Pacific coast of our own continent.

Tertiary deposits in Europe are alleged to have supplied three sorts of evidence of this fact: *First*, the bones of man himself; *second*, bones of animals showing incisions or fractures supposed to have been produced by human agency; *third*, chipped flints believed to exhibit marks of design in their production.

A very complete survey of the question of the antiquity of man was published in 1883 by M. Gabriel de Mortillet, one of its most eminent investigators, under the title of Le Préhistorique. In that work he subjected to a most rigid examination all the evidence for Tertiary man, coming under either of these three heads, that had been brought forward up to that date.

The instances of the discovery of human bones in Europe were two—at Colle del Vento, in Savona, and Castenedolo, near Brescia, both in Italy. At the former site, in a Pliocene marine deposit abounding in fossil oysters and containing some *scattered* bones of fossil mammals, a human skeleton was found *with the bones lying in their natural connection.* Mortillet, however, and many others regard this as an instance of a subsequent interment rather than as proof that the man lived in Pliocene times.* At Castenedolo, in a similar marine Pliocene formation, on three different occasions human skeletons have been discovered, but in different strata. One investigator has accounted for these as the result of a shipwreck in the Pliocene period. This bold hypothesis not only requires that man should have been sufficiently advanced at that very remote period to have navigated the sea, but it calls for two shipwrecks, at different times, at the same point. It has, however, since been abandoned by its author in favor of the presumption of subsequent interments, as in the previous instance. †

* This is also the opinion of Hamy, *Précis de Paléontologie Humaine*, p. 67. Professor Le Conte, *Elements of Geology* (third edition, 1891), p. 609, is wrong in attributing the opposite conclusion to Hamy, on the evidence of "flint implements found in this locality."

† Bullettino di Paletnologia Italiana, tome xv, p. 109 (August 18, 1889).

Animal bones showing cuts or breaks supposed to be the work of man have been found in seventeen different localities in Europe. They can all, however, be accounted for as the result of natural movements or pressure of the soil acting in connection with sharp substances, like fractured flints, or else as having been made by the teeth of sharks, whose fossil remains are found in great abundance in the same formation.

All the discoveries of flints supposed to show traces of intentional chipping are pronounced to be unsatisfactory, with the exception of those found in three localities—Thenay (near Tours) and Puy-Courny (near Aurillac), in France, and Otta, in the valley of the Tagus, in Portugal. As European archæologists at the present time are substantially in accord with Mortillet in restricting the discussion to these three places, I will follow their example. But although Mortillet believes that flints found at all these localities exhibit marks of intelligent action, he will not admit that they are the work of man. He attributes them to an intelligent ancestor of man, whom he calls by the name of anthropopithecus, or the precursor of man. Of this creature he distinguishes three different species, named respectively after the discoverers of the flints in the three localities just mentioned. The precursor, however, has found up to this time only a very limited acceptance among men of science, although a few believe in him on purely theoretical grounds. The discussion generally turns upon the question whether these flints were chipped intentionally or are the result of natural causes; and also upon the determination of the geological age of the formations in which they are found.

I visited Thenay, the most celebrated of these three localities, in 1877, and had the advantage of studying the question there under the guidance of the late Abbé Bourgeois, the discoverer of the flints, and one of the most prominent advocates of the Tertiary man. This was the year before he died, and he showed me at the time his complete collection, and gave me several of the objects he had discovered. Geologists are agreed in assigning the deposits in which they occur to the lower Miocene or middle Tertiary period, which restricts the discussion to the character of the flints

themselves. The accompanying woodcut * gives some indication of their appearance, although it is misleading, because

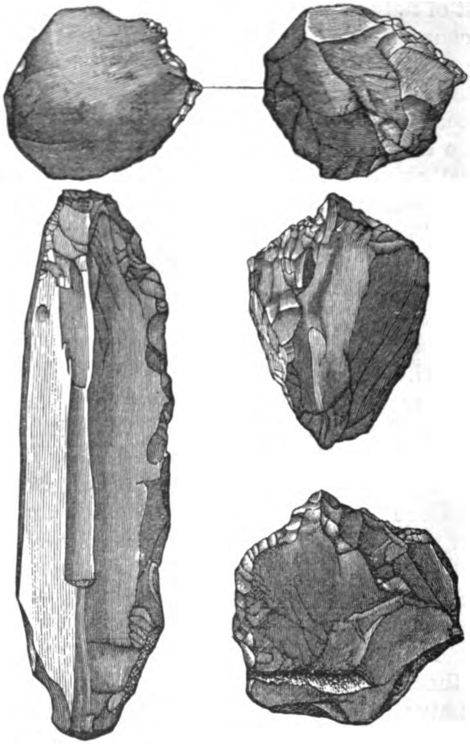

Fig. 108.—Flint flakes collected by Abbé Bourgeois from Miocene strata at Thenay (after Gaudry). Natural size.

the long figure resembling a flint knife is intended to represent a solid nucleus. None of these objects, however, ought to be called "flints flakes," as very few, if any, *flakes* show

* From Le Conte, *op. cit.*, p. 608. The figures are copied from Gaudry, who borrowed them from the article by Bourgeois, *Congrès Internat. de Bruxelles*, 1872, p. 89, pl. ii; and from his *La Question de l'Homme Tertiare.* Revue des Questions Scientifiques, 1877, p. 15.

ing the "bulb of percussion," always seen upon them, have been discovered in the Tertiary deposits at Thenay,* although I have found them there myself *upon the surface.* The three other figures would be classed by archæologists as "piercers," as Bourgeois has himself designated them, and are also solid objects. Many of the Thenay flints exhibit a "crackled" appearance, due to the action of heat. On this account Mortillet maintains that they were splintered by fire, and not formed by percussion, the usual method by which flint implements were fabricated in the stone age. The Thenay objects are all of very small dimensions, and are so absolutely unlike the large, rudely-chipped axes of the Chellean type, found in so many different parts of the world, and generally accepted as the implement used by Palæolithic man, that the question naturally suggests itself, What could have been the purpose for which these little implements were employed? No better answer has been suggested than the ludicrous one that they were used by the hairy anthropopithecus to rid himself of the vermin with which he was infested.

But, leaving aside the question of their purpose, let us consider the evidence presented by the flints themselves. Do they exhibit the unmistakable traces of intentional chipping produced by a series of slight blows or thrusts, delivered in regular succession and in the same direction, with the result of forming a distinctly marked edge? And does the appearance of the action of fire upon their surface imply the intervention of intelligence? To both questions M. Adrien Arcelin, the well-known geologist of Mâcon, has given very sufficient replies in the negative. He has discovered numerous objects of precisely similar appearance in Eocene deposits in the neighborhood of Mâcon.† But, instead of pushing man back on this account so much further into the past, he accounts for the marks of chipping to be seen on many of these objects as the result of the accidental shocks of one stone against another in the countless

* Le Préhistorique, p. 91.

† Matériaux pour l'Histoire Prim. et Nat. de l'Homme, tome xix, p. 193.

overturnings and movements to which the strata have been subjected during the long ages of geological time. He gives photographs of some of these objects, which are to me entirely convincing, and describes how he has surprised Nature in the very act of fabricating them in an abandoned quarry worked in an Eocene deposit. He thinks the "crackled" surfaces can be readily explained as the result of atmospheric action, or of hot springs charged with silex. Numerous examples of similar changes in the surface of flint, that have been noticed by himself and others in different localities, are instanced. Even if some have been caused by fire, this does not necessarily imply the intervention of man to have produced it. Similar discoveries have also been made by M. d'Ault de Mesnil, at Thenay, in Eocene deposits,* and by M. Paul Cabanne, in the Gironde.† My own opinion, based upon the experience of many years spent in the study of flints broken naturally as well as artificially, and upon a careful examination of Bourgeois's collections, is that the so-called Thenay flints are the result of natural causes.

The second locality where flints alleged to display marks of human action have been found is the vicinity of Aurillac, in the Auvergne, especially on the flanks of a hill called Puy-Courny. They occur in a conglomerate of the upper Miocene period, and are consequently much later than the Thenay flints. In this conglomerate, in 1869, M. Tardy discovered a worked flint flake which has every appearance of being artificial.‡ Mortillet, however, says that it was found in the upper surface of the deposit, where there may easily have been a mingling with the Quaternary formation; and it certainly resembles worked flakes, which are not uncommon in the Quaternary. The geological determination of the find may consequently be regarded as uncertain.

The flints discovered at Puy-Courny by M. Rames are of small dimensions, and have all been produced by percussion. Many of them are said to bear some resemblance to pointed

* Matériaux, ibid., p. 246. † *Id.*, tome xxii, p. 205.

‡ See Matériaux, tome vi, p. 94. S. Reinach, however, *Description Raison. du Musée de Saint-Germain-en-Laye*, i, p. 107, n. 8, calls it "gravure inexacte."

flakes of artificial origin, and one has been figured, probably selected for its excellence.* It is by no means convincing to me, and I am not at all surprised that so many archæologists question the artificial character of these objects, which exhibit a great variety of forms. Upon this point Rames does not profess to be qualified to pronounce judgment, limiting himself solely to the geological questions. He argues, however, that the fact that all the objects supposed to be artificial are made of the best qualities of flint, of which implements are ordinarily made, although fragments of inferior quality are abundant in the same formation, implies the intervention of man's judgment in making the selection. But M. Boule shows that this is merely the result of the erosion of an ancient river, which operated only upon the upper beds, in which alone the better qualities of flint are to be found; and Rames has accepted this explanation.† The flints of Puy-Courny seem to fall within the same category as those of Thenay. They are the product of denudation, have travelled long distances, and have been subjected to the action of powerful agents. These causes are sufficient to account for the shocks of which they show the traces, and to explain the production of splinters arising therefrom.

The last locality in which flints claimed to have been manufactured by the Tertiary man are supposed to have been discovered is the so-called desert of Otta, in the valley of the Tagus, not far from Lisbon.

The formation there is a lacustrine deposit of great thickness, belonging to the upper Miocene, and abounding in flint. Here, during the course of twenty years, M. Ribeiro discovered, but mostly upon the surface, a large number of flakes of flint and quartzite. After much debate in regard to them, ninety-five of them were finally sent by him to Paris, in 1878, and placed in the archæological department of the great exposition. There they were to be submitted to the judgment of the assembled prehistoric archæologists of all nationalities, many of whom, including the writer, availed themselves of the opportunity of carefully

* Matériaux, tome xviii, p. 400.

† Revue d'Anthropologie (third series), tome iv, p. 217.

studying them. The judgment of Mortillet is that twenty-two specimens exhibited unmistakable traces of intentional chipping, in which opinion I entirely concur. Only nine, however, were represented as coming from the Miocene, some of which showed on their surface an incrustation of grit, which was claimed as proof of their origin. But the opinion was freely expressed that, even if they really came from the Miocene deposits, they might have penetrated into them from the surface, through cracks, and thus have become so incrusted. It was accordingly resolved to hold the next international congress of prehistoric archæologists at Lisbon, in 1880, mainly for the purpose of settling this question, if possible, by an investigation conducted upon the spot. In the course of a visit made at that time to Otta, several artificial specimens were found on the surface by different searchers, but Professor Bellucci, of Perugia, was fortunate enough to discover a flint flake *in situ*, still so closely imbedded in the deposit that it required to be detached by a hammer. There is no question that this object was actually found in a Miocene deposit, but unfortunately it belongs to the doubtful category of external flakes, which, although they exhibit the "bulb of percussion," have no other sure indication that they are the work of man.* As such bulbs can be produced by natural causes, some stronger proof than this of the existence of Tertiary man is demanded.

These are all the localities in Europe claimed by Mortillet to have furnished such evidence, but he thinks a strong confirmation of it is afforded by certain discoveries made in the auriferous gravels of California. I will not occupy space here in repeating arguments I have brought forward elsewhere to show the utter insufficiency of this evidence to prove the existence of man on the Pacific coast of our continent during the Pliocene period.† They may all be summed up in the words of Le Conte : "The doubts in regard to this

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* It has been figured by Bellucci, *Archivio per l'Anthropologia e la Etnologia di Firenze*, tome xi, p. 12, tav. iv, fig. 2. To me it possesses no value as evidence.

† *The Prehistoric Archæology of North America*, Narrative and Critical History of America, vol. i, pp. 350–356.

extreme antiquity of man are of three kinds, viz.: 1. Doubts as to the Pliocene age of the gravels—they may be early Quaternary. 2. Doubts as to the authenticity of the finds—no scientist having seen any of them *in situ*. 3. Doubts as to the undisturbed conditions of the gravels, for auriferous gravels are especially liable to disturbance. The character of the implements said to have been found gives peculiar emphasis to this last doubt, *for they are not Palæolithic*, but *Neolithic*."* The question has been raised whether this archæological objection is applicable to the stone mortars, numerous examples of which have been found in the gravels, some of them quite recently.† If the evidence brought forward by Professor Whitney and others were limited to these mortars, it might very well be claimed that they are neither Palæolithic nor Neolithic; that the smoothness of their surface is owing to their having been hollowed out of pebbles that have been polished and worn by natural forces. But Professor Whitney has cited numberless instances of "spear-heads," "arrow-heads," "discoidal stones," "stone beads," and "a hatchet" that have been found under precisely similar conditions as the mortars. So Mr. Becker has recently produced an affidavit of a certain Mr. Neale that in a tunnel run into the gravel in 1877 "between two hundred and three hundred feet beyond the edge of the solid lava, he saw several spear-heads nearly one foot in length."‡ Now it cannot be questioned that such objects as these clearly belong to the Neolithic period, which does not imply that all the objects used at that time were polished, but that together with chipped implements "polished stone implements were *also* used."# No archæologist will believe that, while Palæolithic man has not yet been discovered in the Tertiary deposits of western Europe, the works of Neolithic man have

* Le Conte, *op. cit.*, p. 614.

† Professor George Frederick Wright, *Prehistoric Man on the Pacific Coast*, Atlantic Monthly, April, 1891, p. 512; *Table Mountain Archæology*, Nation, May 21, 1891, p. 419.

‡ *Antiquities from under Tuolome Table Mountain in California*, Bulletin of the Geological Society of America, vol. ii, p. 192.

Le Conte, *op. cit.*, p. 607.

been found in similar deposits in western America. Peculiar difficulties seem to surround the evidence brought forward in support of such an assumption. We are told by Professor Whitney that a stone mortar was "found standing upright, and the pestle was in it, in its proper place, just as it had been left by the owner." He fails, however, to explain how this was brought about in a gravel deposit supposed to have been laid down by great floods of water. So, when Mr. Neale swears that he saw fifteen years ago in the same gravels spear-heads a great deal larger than those known to archæologists, may we not ask whether reliance can be placed on the memory of witnesses who testify to impossibilities to justify conclusions that rest upon such testimony?

I think we shall have to wait for further and better evidence than this before we are called upon to admit that the existence of the Tertiary man upon our Pacific coast has been established.

[illegible] America, &c
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